February 1993

BEST PRACTICE PROGRAMME

Good Practice Guide 61

Design Manual

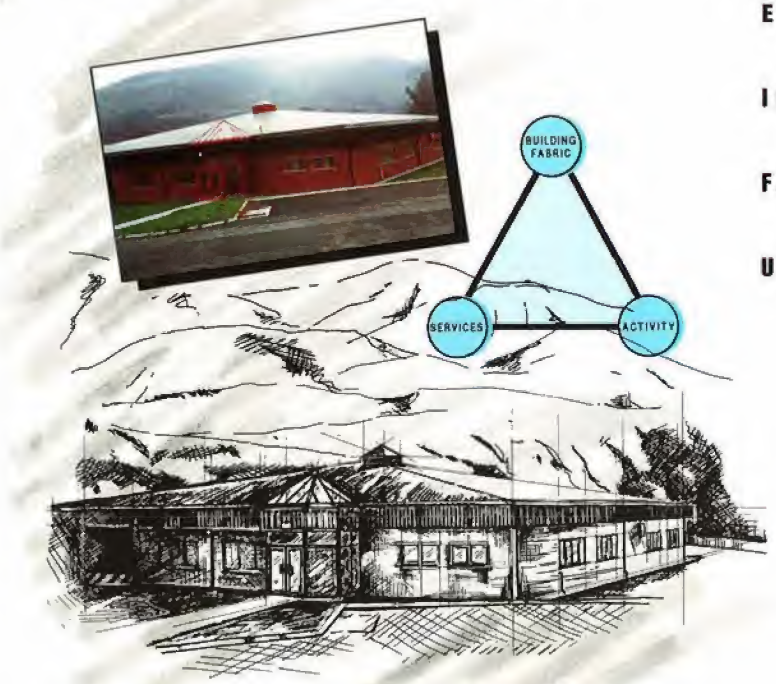
ENERGY

EFFICIENCY

IN ADVANCE

FACTORY

UNITS



Building Research Establishment

Energy Efficiency Office
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Good Practice Guide 61

Design Manual

Energy Efficiency in Advance Factory Units

Preparation managed for the Energy Efficiency Office by:
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February 1993

Energy Efficiency Best Practice programme publications

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Preface

This guide is one of a series of Energy Efficiency Office (EEO) publications concerned with *Energy Efficiency in Advance Factory Units*. The other publications are:

- **Occupiers Manual**: A summary document for occupiers, outlining selection of building, and preparation of brief for environmental services to match activity and building fabric.

- **Good Practice Case Studies**: Assessment of Advance Factory Units which incorporate energy efficiency measures.

These documents are the result of comprehensive investigation into the achievement of energy efficiency in Advance Factory Units (AFUs) and form part of the Energy Efficiency Best Practice programme promoted by the EEO to advance and spread ways of improving the efficiency with which energy is used in the UK.

The Welsh Development Agency has been at the forefront of development of energy efficient AFUs by constructing buildings to improved standards for little extra capital cost. A previous EEO study showed that these buildings have achieved substantial savings in energy consumption compared with buildings constructed to standards of the then current Building Regulations.

This document gives pratical guidance in the planning development, fit-out and use of AFUs in order to achieve the efficient use of energy.

Although compiled specifically for AFUs, where the end use is generally not known, this information can also be used, where applicable, for Bespoke Factories with a defined activity.

Acknowledgements

The Guide has been prepared by W S Atkins Consultants Ltd with the assistance of an Advisory Panel, and reviewed by Building Research Establishment (BRE) and many other organisations.

The Chartered Institution of Building Services Engineers (CIBSE) has permitted the use of some extracts from CIBSE Guides.

CONTENTS

Summary

Previous work has indicated the potential benefits of low energy factory development, built to standards improving on those for the 1990 Building Regulations. The Welsh Development Agency and the Development Board for Rural Wales, in particular, have been at the forefront of developing the low energy concept on a commercial basis.

This Guide has been compiled to bring together the wealth of practical experience gained by these and other organisations in the development of low energy Advance Factory Units (AFUs), with examples of good practice design and construction for the benefit of a wider audience.

It is intended to be a reference manual for use by property developers, architects, designers, consultants and contractors involved with the construction of AFUs, and the installation of environmental services.

The Guide is divided into two separate sections:

Part A: Design and construction of Advance Factory Units

The scope is the design and construction of the AFU structure and envelope.

The target audiences are:

- Architects
- Designers
- Developers - private and public sector
- Contractors.

The emphasis is on the importance of *quality* of:

- Design, including detailing
- Construction
- Built-standard validation, comprising on-site testing for quality assurance.

Part B: Selection of environmental services for Advance Factory Units

The scope includes the design and installation of environmental services in the Office Area and Production Area, and any fabric fit-out associated with the reduction of the heating load.

The target audiences are as follows:

- For specific advice:

  Mechanical and electrical consultants, either employed by the developer (before the end use is known) or employed by the occupier

  Mechanical and electrical contractors.

- For general advice:

  Architects

  Developers

  'Informed' occupiers.

Both Part A and Part B are based on the concept of *cohesive design*, which stresses the importance of the interactions among the building fabric, installed services, and the activities and processes carried out in the building. This is illustrated by the diagram below.

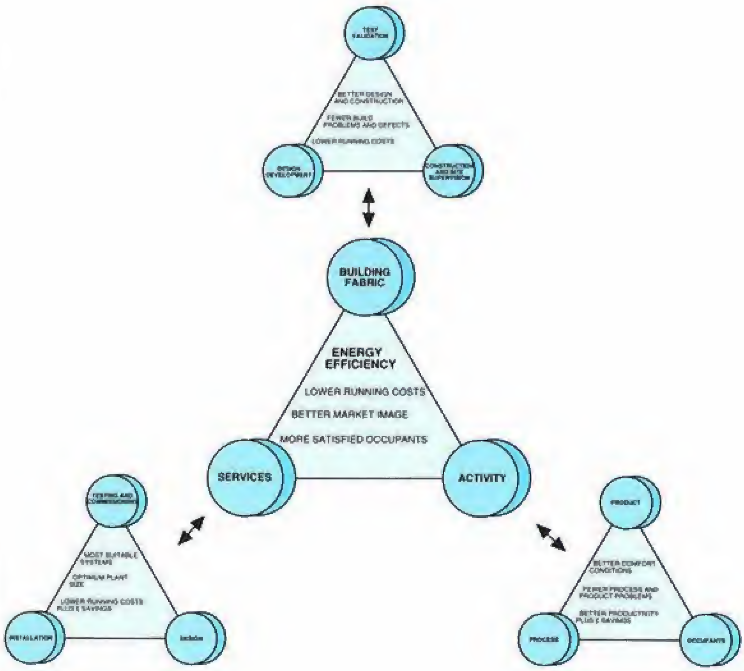
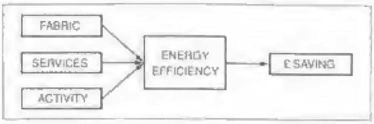


Figure 1(a) Cohesive design

The Guide is laid out in modular format, enabling easy reference of relevant information. A series of key charts is used to outline the options available. Each referenced option is described in more detail, outlining the advantages and disadvantages of use, the implications for other elements of the building, and specific points to consider.

Introduction



i Why is efficient use of energy important?

Over the past few years, there has been a great increase in the public awareness of environmental issues, and hence there are many advantages in a building that is environmentally friendly in terms of a green image, with consequent opportunities for marketing. This is likely to become increasingly important in the future.

It is also likely that fuel costs will rise over the next few years as fossil fuel resources diminish. Therefore, features or systems incorporated into a building at the beginning of occupancy to reduce energy consumption will become increasingly beneficial.

On a global scale, the conservative use of energy has become more important, both in terms of consumption of fossil fuels and production of carbon dioxide and other greenhouse gases. The pressures to improve our performance in these areas can only become greater as resources of fossil fuels diminish and levels of greenhouse gases increase.

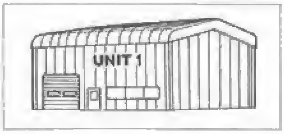
These pressures to improve our efficiency in the use of energy are likely to be augmented by legislation involving such routes as energy use targets.

A reduction in energy consumption brought about by the improvement in energy efficiency will reduce overheads and hence raise individual competitiveness. On a national scale, the performance of the industrial base as a whole will be improved.

At present, it is recognised that energy costs form a relatively small proportion of an occupier's operating costs. With rising energy costs, this proportion will assume greater significance. Energy cost savings translate directly into larger profits for the occupant.

Significant gains in energy efficiency in Advance Factory Units (AFUs) can be made without incurring large capital cost penalties[1,3-7].

ii What is an Advance Factory Unit?



AFUs are designed and built by developers and development agencies to provide ready-built industrial space for early or immediate occupation.

Normally, the end use is unknown during development. Flexibility of use is provided over a wide range of light industrial, servicing, and warehousing activities.

A typical AFU comprises an Office Area occupying a small proportion of the total space and a Production Area served by goods door(s).

The height to eaves is generally 6m ($19.7ft^2$) although for smaller units may be as low as 4.5m ($14.8ft^2$). Unit sizes can be categorised as:

small:	less than $930m^2$	($10\,000ft^2$)
medium:	$930\text{-}1860m^2$	($10\,000 - 20\,000ft^2$)
large:	more than $1860m^2$	($20\,000ft^2$).

Usually, the Office Area is fully serviced by the property developers with heating, ventilation and lighting. On all but the smallest units, normally no services are provided in the Production Area other than trunking for lighting installation and mains services for heating installations. However, in some instances the prospective occupier may arrange with the property developer for full installation of services.

iii How to achieve an energy efficient Advance Factory Unit

With a few notable exceptions, energy efficiency in AFUs generally receives a lower priority in comparison with consideration of energy efficiency for office accommodation or housing.

The objective should be to treat the development and use of an AFU as a cohesive whole, rather than as a number of piecemeal items.

In order to illustrate this goal the concept of *cohesive design* is introduced below and developed in more detail in the following Section.

The key description of the concept which must be applied in practice is *cohesive* - each step in the sequences of planning, design, construction and use is inter-related. All planning and design decisions must be taken with recognition of the consequences on the performance of the building, both in terms of running cost (energy efficiency) and in terms of wider environmental impact, ie sourcing of materials, longevity etc.

At this planning stage, it is important to involve all the relevant parties, including the building services consultant or designer. This will enable the building fabric to be designed to minimise energy consumption and to be flexible enough to accommodate a range of future services installations. The choice of the latter will, in turn, depend upon the end use.

It is at this early stage of development that the potential energy efficiency of the building fabric will be determined. Proper consideration of the influencing factors will have a large effect on the attainment of energy efficiency; conversely, the incorporation of poor features will have a detrimental effect which cannot be compensated for later on.

Achievement of an energy efficient building requires adequate individual attention to the three principal elements which affect building performance. Just as importantly, consider how these elements interact in the building system. The three elements are:

- **Building fabric** - the structure and envelope
- **Services** - the mechanical and electrical systems installed to control the environment within the building space
- **Activity** - the work that the occupier undertakes in the various areas of the building.

The interactions among the three elements above are represented by the central triangle in Figure 1.

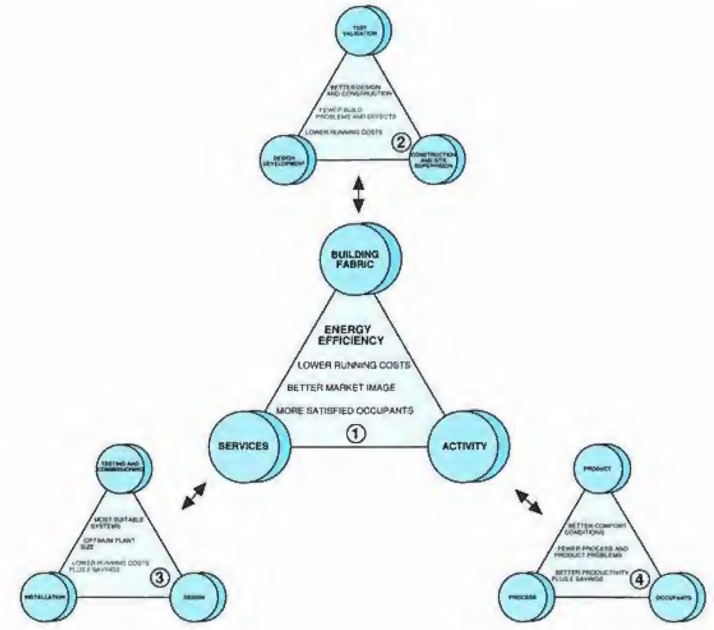


Figure 1(b) Cohesive design

iv Cohesive design elements

- **Building fabric** (See Figure 1(b), Triangles 1 and 2)

  Energy efficient building fabric can be achieved by considering each of the following:

  Design development

  Design the fabric of the building to match the performance standards required over the full life of the building, whilst minimising susceptibility to possible problems such as interstitial condensation, excessive infiltration loss, accidental damage etc.

  Give careful thought to the likelihood of degradation over the design life of the building of the materials, fixings, connections, sealing methods etc.

  Consider carefully the buildability of details and cladding systems with regard to the conditions on site during construction.

  Consider how to restrict uncontrolled infiltration through the structure, particularly at eaves, ridges and floor junctions, and also at goods doors, personnel doors and windows. With the introduction of improved insulation values required by the Building Regulations, generally this is the predominant source of heat loss.

  Carefully select the area, orientation and location of windows and rooflights to optimise levels of daylight with fabric transmission heat loss.

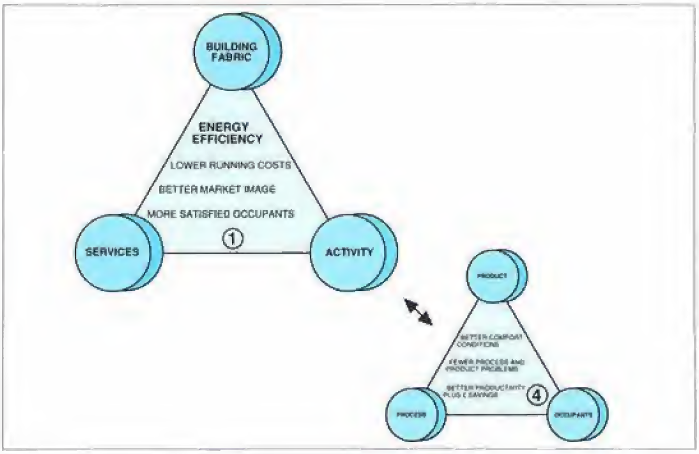
Construction and site supervision

It is particularly important that site supervision ensures that the building is constructed as designed. Poor quality construction can negate any benefits arising from careful design.

Test validation

An important contribution to achievement of energy efficiency arises from the verification of the design and construction standard, by means of thermographic surveys and U-value tests. As yet, these tests are not carried out as part of commercial contracts, except for Welsh Development Agency AFUs. The techniques for testing, and the case for inclusion in build contracts, are given in Section vi.

- **Activity** (See Page 5, Triangles 1 and 4)



Achievement of energy efficiency must not be at the expense of the needs of the **process, product or occupants of the building**. A pre-requisite for the design of the services is that there is an appraisal of requirements dictated by the activity in terms of levels, and zoning, needed for:

space temperature

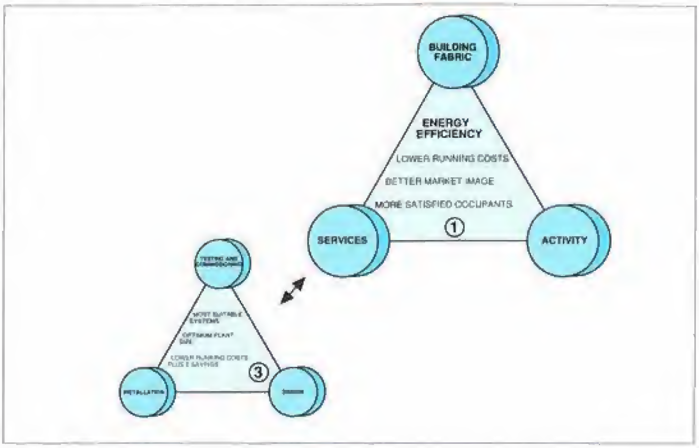
humidity (if relevant)

ventilation

lighting

noise levels.

- **Services** (See Page 5, Triangles 1 and 3)



Generally, the mechanical and electrical systems in the Production Area in an AFU are designed and installed under a tenant fit-out contract. The Office Area is usually fully serviced as part of the main contract. Increasingly, occupants are expecting improved comfort conditions for the Production Area of an AFU, approaching those demanded in the Office Area. This is mainly owing to the predominance of light industry in this sector, for which the activity approaches sedentary office-type working. These demands equate to a number of criteria for the mechanical services designer:

maintenance of design temperature within agreed limits

control of air velocity to avoid draughts and stuffiness

avoidance of large vertical temperature gradients and high, or fluctuating, radiant temperatures.

Firstly, achieve selection of the most suitable systems by considering the interactions with the building fabric:

fabric heat loss quantified accurately and confirmed subsequently by validation tests

infiltration losses controlled and quantified

natural light levels assessed.

Secondly, consider the interactions with the activity in terms of suitable types of system for:

heating (radiant, convective, mixed)

cooling (if relevant)

ventilation (dust and contamination effects; fresh air requirements)

lighting (quantity and quality of light)

noise levels (need for acoustic treatment).

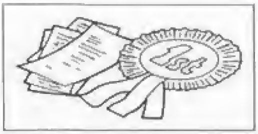
Having undertaken this procedure of interactive selection, ensure proper performance of the systems by:

careful **design**, eg layout of space heating units to avoid hot and cold spots, consideration of lighting controls to take account of daylight levels and occupancy times where appropriate

correct **installation**, to ensure design performance

testing and commissioning, to confirm correct performance levels.

v Benefits of cohesive design

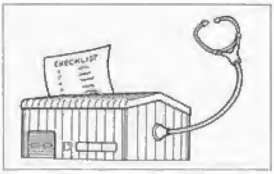


The implementation of *cohesive design* principles has benefits for all parties concerned:

- The team of developers, architects, building services engineers and builders then constructs buildings which should be more marketable as a result of the building validation tests providing 'proof' of design and construction standard. Fewer defects should result, and the need for expensive remedial works should reduce.

- Ensuring good design and correct construction practice will enable the occupant to acquire a building for which he can match the services installations to both the fabric loads and requirements of the activity. This will achieve satisfactory environmental conditions, lower running costs, higher staff morale, and fewer complaints about faults in the building fabric such as roof leaks, excessive heat loss and condensation.

vi Validation checklists and building tests on completion



An energy efficient building envelope depends upon achieving *quality* of:

- Design
- Construction
- Built-standard verification, ie on-site testing. This is needed for quality assurance and it could be said that this is the 'weak link' at present. Previous work[2,3,5] has shown that design overall U-values are not always achieved in practice.

The recent improvements in thermal performance standards and infiltration control mean that the effects of any faults in the detailing, or in the construction, will be magnified, resulting in a larger effect on thermal performance. Therefore, it is becoming more important to verify the built-standard to ensure that the thermal performance matches the design predictions. This is especially important in the context of reducing the heating plant capacity to match design heat losses more closely, under the concept of *cohesive design*.

At present, the quality control of the construction of buildings is carried out by the Clerk of Works on-site. It is difficult to ensure good quality in all areas all of the time, and this is especially so on a large site or in poor weather conditions.

For built-standard verification, in addition to the building tests outlined below, introduce a system of checklists. Each design party (architectural, structural, civil, and services) should draw up checklists for the Clerk of Works and/or Site Engineers to check and sign off. Through this system, the Clerk of Works will become aware of any specific points to look for in that element of the project.

The checklists could include records of:

- Weather conditions
- Construction process completions (eg, is loading bay door frame sealed to builder's work opening, or are all fillets in place?)

Copies of the checklists, along with the site test results described below could be made part of the documentation handover to the building owner on completion.

Use of verification techniques described below enables straightforward and accurate checking of the design *and* construction standard of any heated building. Further details of these tests are given in Appendix A.

- **Infra-red thermographic surveys**

  A hand-held infra-red scanner is used to detect infra-red radiation emitted by objects and surfaces. The technique enables visualisation of:

  areas of missing or defective insulation

  cold bridging at sheeting rails, internal gutters etc

  infiltration around goods doors, windows, and poor junction details

  missing or defective seals, fillets etc.

  The survey is normally carried out from inside and outside the heated building, and usually can be completed within 2-3 hours. It is simple to carry out and is relatively inexpensive.

  For larger sites or groups of buildings, an aerial thermographic survey may be worth considering. However, the level of detail obtained will not be as great in most cases.

- **U-value test**

  The U-value of a roof or wall can be assessed by monitoring the heat flow through a representative area of the surface. An average value is taken by recording the varying conditions on dataloggers over a period of 7-10 days.

- **Infiltration rate tests**

  Two methods exist for measurement of the ventilation rate of a building:

  pressurisation test

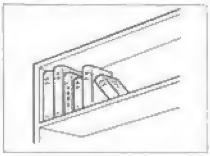
  tracer gas decay test.

  However, external conditions give considerable variance to the test results. Whilst useful for research purposes, at present the techniques are not considered suitable for standard commercial applications. Methods are continuing to be developed to improve the repeatability of the tests.

The Welsh Development Agency has been at the forefront of extending these validation techniques to commercial development by including infra-red thermographic surveys of completed buildings as a requirement of construction contracts. This activity alone has resulted in a substantial improvement in built quality, particularly with regard to the installation of insulation. The intention is to include a U-value measurement as part of the building contract requirements also.

One of the aims of this Guide is to advocate the general introduction of thermographic surveys as part of the building contract. This is seen as the most cost effective method of improving built-quality standards.

vii References



- **General**

1 **Jones P J and O'Sullivan P E.** Energy efficient design of industrial buildings. *Building and Environment*, 1987, **22** (3), 181-187.

2 **Jones P J**. Low energy factories: 2 Building fabric. *The Architects' Journal*, 1990, **191** (20) 67-69.

3 **Hughes D.** Energy efficient factories: design and performance. *Building Research Establishment Information Paper* IP 13/89. Garston, BRE, 1989.

- **Guidance publications - Energy Efficiency Office**

Available *free* from **Building Research Energy Conservation Support Unit (BRECSU)**, Building Research Establishment, Garston, Watford, WD2 7JR; tel 0923 664258; fax 0923 664097.

4	Low energy factory development.	EPP 173.
5	Low energy factory development.	Final Report No. ED/256/173.
6	Insulated loading doors.	EPP 334.
7	Energy efficiency in industrial buildings.	IL9.

PART A
DESIGN AND CONSTRUCTION OF ADVANCE FACTORY UNITS

PART A - DESIGN AND CONSTRUCTION OF ADVANCE FACTORY UNITS

Contents

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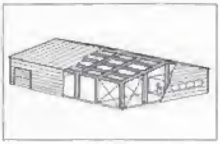
1 Introduction

Part A of the Guide concerns the planning, design and development of the building fabric. The target audiences are:

- Architects
- Designers
- Developers - private and public sector
- Contractors.

Referring to Figure 1, it is recognised that, generally, at the planning stage of development, the end use of the unit is unknown, and the services for the Production Area have not been selected. Therefore, the priority is to ensure flexibility, by catering for a wide range of end uses and enabling a wide range of services to be installed. Hence, the emphasis in Part A is in producing a building of good quality design and construction standards, proven by verification tests.

2 Advance Factory Unit design and construction type

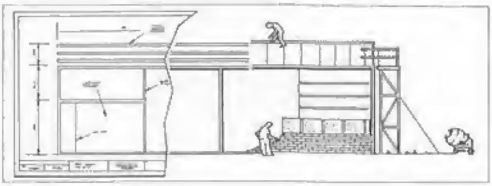


The typical AFU described in this Guide is based on the type which forms the majority of units now in use in the UK. The major design and construction features are:

- Building envelope enclosing the Production Area and a small proportion of Office Area.
- Goods door(s), relatively large, serving the Production Area.
- Steel frame
- Cladding or masonry walls
- Cladding roof (or, in a small proportion of cases, tile or slate roofs)
- Concrete floor slab.

Alternative forms of construction are also used and, in general terms, the advice contained in this Guide can be applied to these forms also.

3 Building development



At each stage of the development sequence, make sure all relevant factors are identified for consideration. The list below is not intended to be exhaustive; rather, the purpose is to stimulate the formulation of ideas, keeping the goal of energy efficiency and building quality to the fore. For further guidance, refer to the *British Standard Code of practice for energy efficiency in buildings*[2].

3.1 Concept stage

3.1.1 General

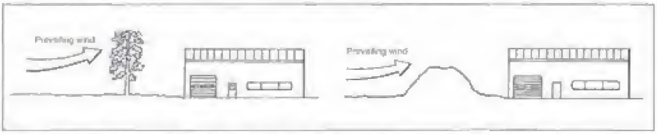
From the outset take full account of:

- **Product policy:** Examine the developer's policy regarding use of environmentally friendly products. If no such policy exists, establish project-specific principles.

- **Quality:** Establish the means by which as-built performance can achieve the design standard. Consider the use of thermographic surveys and allow for these costs.

3.1.2 Site planning

- **Site exposure** can have a significant impact on the demands on the environmental systems within the building[7]. In severely exposed sites, the control of infiltration losses assumes greater importance if the capital and running costs of energy systems are to be minimised. Consider utilising trees and banks as windbreaks, either by natural site features or by landscaping.



- **Orientation and location** of the building on a site needs careful attention, particularly the position of:

  Large goods doors, in relation to prevailing wind direction.

  Glazing, in order to provide good daylighting whilst avoiding excessive solar gain through south facing glazing, especially in the Office Area. This factor has become increasingly important with the introduction of higher insulation values. The shading effect of adjoining buildings also needs consideration[10].

3.1.3 Costs planning

Capital and running costs: The capital cost of any energy efficiency measure is likely to be the overriding factor controlling choice. However, it is important to consider the reduction in energy use and hence running cost. If this can be calculated, and compared with the cost of running a standard system or building, then a marketing advantage can be derived. The financial effect of each design choice available should be assessed in this way, by developing a suitable cost analysis system.

3.1.4 Construction planning

- **Available skills:** Structural or mechanical systems which require specialist skills to install, need careful appraisal of the increased cost, and effect on timescales.

- **Construction period:** Consider the effect of incorporating energy efficient features, materials, or systems, in the building design; but any increase in the construction period time scale must be held in perspective. The inclusion of such measures may increase time on site by, say, 10%, but the construction period is, itself, often a relatively small period in the overall project programme (which might include inception, funding, planning, design and finally construction).

- **Building design:** Current AFU practice normally employs a standard height to eaves and minimum standards of insulation to satisfy statutory requirements. Before such criteria are automatically adopted, there is a need to carefully establish, in discussion with all parties concerned, the optimum design solution for each specific development. Use *cohesive design* principles to correlate building volume, insulation standards, and energy systems with capital and running costs.

- **Flexibility of internal layout:** This must be maintained; if draught lobbies at goods door positions are not incorporated by the developer, the space to install these should be allowed for at this stage.

3.2 Design stage

3.2.1 General factors

- **Statutory regulations:** The design must meet all relevant statutory regulations and requirements in all cases.

- **Planning principles:** Use the principles established at the planning stage to develop the detailed design of the unit.

- **Construction process limitations:** Always be mindful of the construction process itself, and how this may affect the design standard: the designer must be sure that the specification can be met in reasonable time, and at reasonable cost. What effect will inclement weather impose? Do the materials require special storage conditions? To what extent does the performance of a given material rely on the standard of workmanship which can reasonably be expected?

3.2.2 Energy use aspects

The diagram below illustrates the distribution of heat losses for a typical medium-sized AFU.

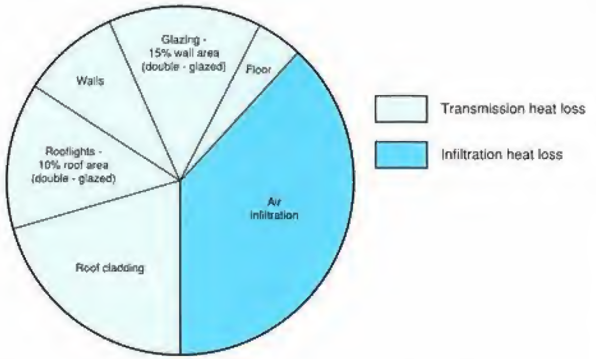


Figure 2 Distribution of heat losses for a typical medium - sized AFU

The diagram highlights the following:

- **Air infiltration** accounts for over a third of the heat loss and hence emphasises the importance of the control of incidental air leakage.

  In designing the building envelope, it is worth considering the outer skin as a weather proofing element, and the inner skin as an air barrier preventing air leakage. Sealing methods should be considered and developed as an integral part of the envelope design. Constructions in which sealing would be difficult to achieve in practice should be avoided.

- **Rooflights**, 10% by area, account for approximately 40% of the roof transmission heat loss. Nevertheless, these can be energy efficient if the daylight provided is used to replace electric lighting through the use of suitable lighting controls. In addition, daylight from rooflights can be of psychological benefit to occupants, by providing a sense of passage of time from the perception of the changes in weather conditions. The area, orientation and location of rooflights need to be chosen carefully to optimise the benefits gained with the increase in heat loss.

- **Glazing**, 15% by area, accounts for approximately 55% of the wall transmission heat loss. Again, glazing can be energy efficient if the daylighting is used effectively: the use of light level detection and automatic lighting controls, particularly for perimeter fittings, can significantly reduce lighting energy consumption.

  Large areas of glazing exacerbate the problem of summer overheating, particularly in southerly facing offices; hence the glazing area should be chosen with care, with shading devices fitted where appropriate. In order to reduce the effect of solar gain, and the increasing use of electronic office equipment, the *opening* area of glazing should be maximised, to enable best use to be made of natural ventilation.

  Careful consideration of the building design, especially the glazing, may avoid the need for wasteful comfort air conditioning.

3.2.3 Materials

- **Performance criteria:** In selecting energy efficient materials, as well as assessing thermal performance and cost, consider the other performance criteria, eg strength, impact resistance, services support, noise attenuation, etc.

- **Fire risk:** Increase in fire risk or compromise of fire rating is generally to be avoided, eg the choice between a high performance, but combustible, insulant compared with a lower performance, inert, alternative. Similarly, such a choice may affect the insurance requirements, and hence the cost of insurance cover.

- **Maintenance and serviceability:** Building materials, which offer increased thermal performance at the expense of inferior damage resistance, or heating systems which need additional maintenance requirements, may not be suitable. If the design performance is significantly affected by damage, or by lack of maintenance, then these materials or systems could adversely affect the full life cycle energy consumption of the building.

- **Energy and environmental impact of manufacture:** The choice of building materials and products should take both the energy requirements and the environmental effects of the manufacturing process into account.

3.2.4 Structural factors

- **Component specification and detailing:** For cladding systems, many manufacturers produce standard details for eaves, ridges and joints with cavity wall construction. However, the majority of uncontrolled infiltration occurs at these locations. Therefore, careful consideration must be given, by the specifier of the cladding system, to the expected performance of standard detail. If performance cannot be guaranteed, specific architectural details may be developed.

- **Durability:** Consider the durability of the details selected, so that heat losses can be controlled over the whole life of the building.

- **Interstitial condensation:** The more stringent comfort conditions demanded by occupants, and the consequent maintenance of higher internal space temperatures, increase the risk of interstitial condensation. Higher standards of insulation can also exacerbate this risk, with the consequent problems of waterlogging of insulant, corrosion and leaks. Avoidance of interstitial condensation is an important factor in the design of roofs. The technical risks associated with these increased standards are explained in detail elsewhere[5].

  Avoid dark coloured roofs, which can increase the likelihood of condensation resulting from radiation to night skies.

3.2.5 Site factors

- **Buildability:** In assessing high performance building materials or fabric systems, consideration of buildability is of paramount importance. Constructions which necessitate abnormally high standards of workmanship or site supervision are less likely to achieve these, and hence are more likely to suffer from construction defects and fail to reach design performance standards.

- **Standards of workmanship:** When choosing among different cladding/wall systems, remember that standards of workmanship cannot be guaranteed at all times. Many site fabricated steel cladding roofs exhibit local high heat losses, caused by missing insulation, typically up to 5% by area. Constructions which do not rely on high standards of workmanship to achieve design performance, are advantageous.

- **Construction defects:** The effect of likely construction defects must be assessed at the design stage. Considering the example of missing insulation mentioned above, the effect of the 5% area of missing insulation has a much greater effect on the increase in heat loss, eg 30% increase in conductive heat loss; in addition there will be increased likelihood of condensation, and attendant problems of corrosion and staining.

3.3 Construction stage

3.3.1 Workmanship

Good quality detailing of the building envelope at the design stage can be lost by poor standard of workmanship in the construction stage,[8,17,19] and hence the value of good site practice cannot be over-emphasised.

3.3.2 Quality verification

Ensuring that quality is achieved is by no means straightforward. However, consideration of energy efficiency through careful design and construction, along with quality verification, enables this goal to be achieved.

The techniques have been outlined in Section vi and are explained more fully in Appendix A.

3.3.3 Build programme

Check that the sequencing of events on site is as envisaged at the design stage. If it is not, ensure that the proposed sequence does not compromise the performance standard required. Consider the imposition of sequencing on the builder at tender stage.

3.3.4 On-site modifications

Ensure that alternative methods or proposals, put forward by the builder, match the design and durability standard required.

3.3.5 Weather factors

Be aware of the effect of inclement weather on the materials in use, particularly the absorbent type of insulant.

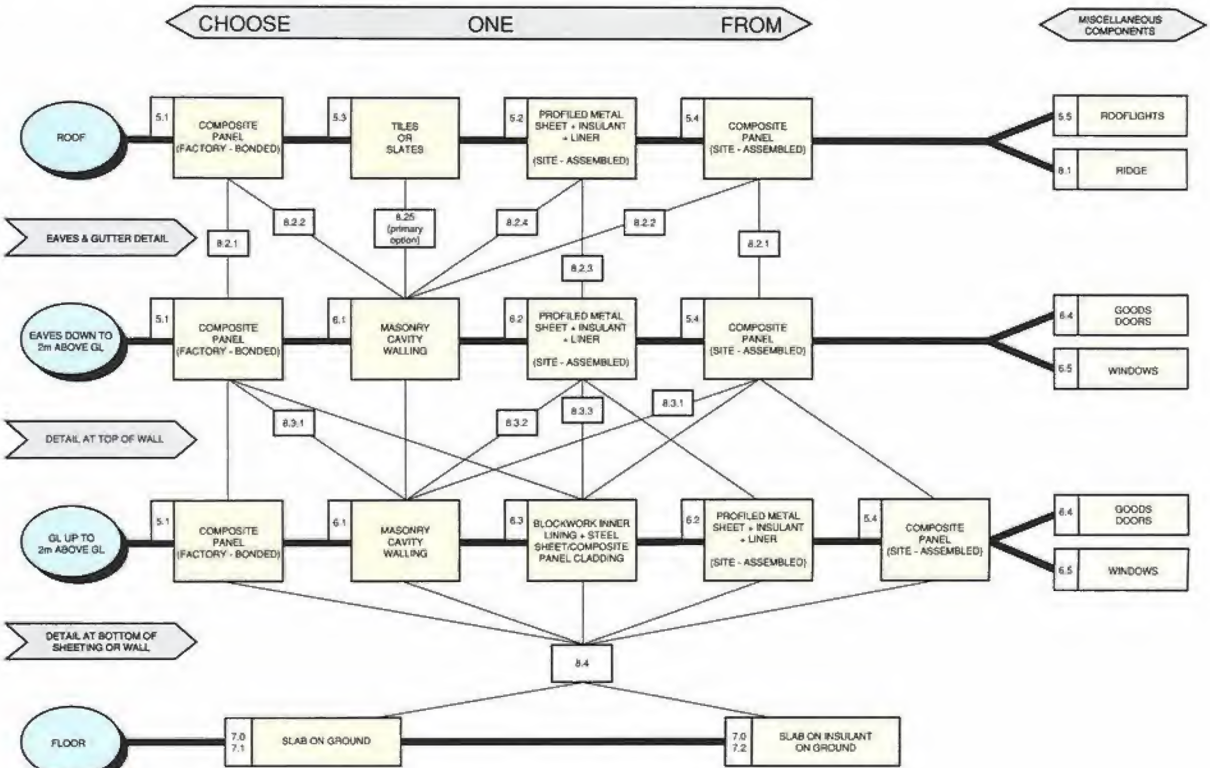
4 Construction element options

4.1 Construction element options - key chart

The chart opposite summarises the options available for each element of the construction. A series of references directs the reader to further details of each option. The junctions between elements are detailed under further references. The technical aspects and problems associated with the joining of the various types of construction are noted.

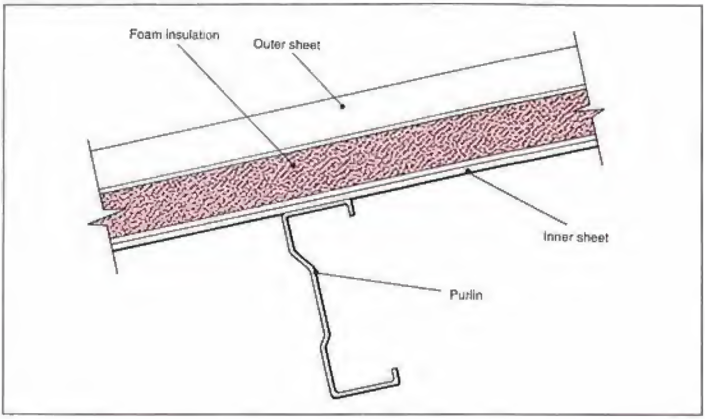
The chart is intended to assist in the development stages of design, by enabling rapid appraisal of options for the structure.

Figure 3 Construction element options - key chart



5 Roof construction

5.1 Factory-bonded composite panel (also applicable to walls)



Description

These panels are factory-assembled and delivered to site, ready for direct fixing to the building structure in roof or wall applications. When used on walls, panels may be arranged to span vertically or horizontally. A technical advisory service for the use of these panels is available from The European Panel Information Centre[26].

Panels comprise a rigid foamed insulant with a metal facing bonded to both faces.

Through-fixed or secret-fixed options are available and a wide range of materials, finishes and profiles are currently available.

External facing normally consists of a galvanised sheet steel or aluminium core, protected on the weather face (or both faces) with specially formulated coatings, which are designed to enhance the durability and colour retention of the facing.

Internal facing, if present, may be of similar standard to the external facing. It is more usually of a lower quality finish, however, such as a decorative paint.

Insulant of various thicknesses, ranging typically from 50mm up to 100mm is available to match the U-values required (see Table below). The material itself is a rigid closed-cell foamed material: chlorofluorocarbon (CFC) free products are now becoming readily available.

Insulant thickness (mm)	Approx U-value (W/m^2K)	Relative spanning capacity *	Relative material cost * +
50	0.40	100	100
60	0.35	106 - 110	105
70	0.30	115 - 120	110
80	0.26	125 - 135	112
100	0.20	140 - 160	185

* 50mm thickness = 100.
+ Does not include savings made in reduced sheeting rail/purlin weights.

Advantages

- In theory, these products are free from vapour carrying air (since the foam is impermeable and no voids are present). Therefore, no condensation can form within the panel, unless the manufacturing process leaves voids within the insulation, and vapour is allowed into the panel.

- The spanning capacity of double-faced panels is generally greater than systems which rely on the structural performance of a single profiled metal sheet. Consequently, rail and purlin spacings can be relatively large; indeed, side sheeting rails can be eliminated completely if the cladding is designed to span horizontally between stanchions. The added advantage of using thicker insulation is that the spanning capacity is proportionately increased (see Table above): up to 60% greater spans can be achieved by using a 100mm panel instead of 50mm panel. In roof applications, the spacing of purlins may be dictated by the spanning capacity of rooflights.

- The highly prefabricated nature of this type of construction can contribute greatly to reducing erection times. This will, of course, lead to faster completion of the weatherproof enclosure, so that follow-on activities can commence at earlier stages of a contract.

- The prefabricated nature of the unit also ensures that no insulation is omitted during construction, and hence the design U-value is always assured.

- Fabric heat losses may be reduced by 35% through using materials costing 12% extra.

- Additional costs may be offset by reduced need for validation, due to confidence in as-built standard of insulation.

Disadvantages

- Cost is invariably considered to be the primary disadvantage of using composites. However, there are many systems available, and consequently a broad price range exists. The designer should carefully balance costs against such considerations as durability of the surface, colour retention, and the advantages of the system outlined above.

- The absence of an air gap in the construction leads to a reduced standard of acoustic performance, which may be important in some applications.

- The designer should seek assurance that the risk of delamination of the facings from insulation is minimised, as the structural performance of a panel depends on the bond between its components; also, that there is no danger of horizontal shear failure in the insulation itself. Solar gain can increase the internal stresses in panels with dark external finishes and may cause blistering or delamination.

- The danger of condensation occurring in the joints between panels must be minimised. Either the insulation must be made effectively continuous across a joint, or the joint needs to be sealed such that vapour is not allowed into the joint.

- Site storage and handling of panels requires very careful attention.

- Cutting of units to fit around obstructions can be more difficult than with other systems.

- Units are sometimes purpose-made and, if these are damaged during construction, can be difficult to replace at short notice.

- Fire-resistance of these systems used on their own is generally poor.

5.2 Profiled metal sheet + insulant + liner (site-assembled)

General description

This family of construction systems consists in broad terms of three elements:

- Profiled metal weather facing
- Insulation layer
- Internal lining.

A variant on this theme is a system comprising a rigid insulating board and profiled metal weather facing which does not require a separate lining. Within this generic type (ie site-assembled 'sandwich'), there are a number of systems available, and some of the more widely-used combinations are described below. The type and thickness of insulation can be chosen to match the performance required: see Table below.

Mineral wool thickness (mm)	Approx U-value (W/m^2K)	Relative material cost (complete sandwich) *
80	0.44	100
100	0.35	102
150	0.24	107

* 80mm thickness = 100

Whichever system of cladding in this category is chosen, it will normally be necessary to incorporate some degree of ventilation into the air gap present, unless the lining system provides an effectively continuous vapour barrier. However, it should be noted that increasing the ventilation in the construction will also significantly increase the thermal transmission rate by short-circuiting the insulative effect of the air gap.

The ventilated air space requires:

- Aperture along the eaves
- Free air passage between the insulation and the outer metal sheeting between eaves and ridge
- Aperture along the ridge.

The risk of condensation occurring on the underside of the outer metal sheet is governed by, *inter alia*:

- Ventilation throughput
- Internal surface temperature of outer metal sheet.

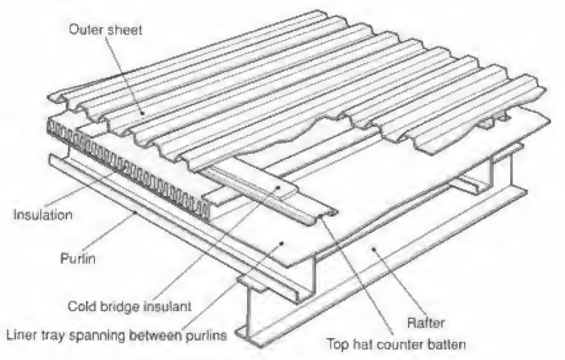
Paradoxically, increasing ventilation throughput, by means of separating the outer sheet from the insulation below, can reduce the surface temperature of the metal sheeting and consequently increase the risk of condensation.

Therefore, it is common practice to install outer sheeting so that troughs are in contact with the insulation, and ventilation is restricted to the air spaces below the crowns. However, the risk of condensation occurring in certain environmental conditions remains significant and if insulation performance is affected by moisture, the effect can be self-perpetuating. The inclusion of a breather paper above the insulation can prevent the passage of condensate back onto the insulation, though the effectiveness of this is doubtful, as the paper needs to be effectively continuous to work properly.

A further alternative is to use an insulant which is unaffected by the presence of water. In any case, the presence of water within the construction can lead to corrosion of metal sheets; in cases where regular condensation is likely, careful selection of reverse-side coatings is of paramount importance.

For this type of cladding, fabric heat losses may be reduced by 45% by using extra insulating material costing an additional 7%.

5.2.1 Profiled metal sheet + insulant + liner tray system



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam or concealed-fix systems, coated with a range of high quality, colour protective finishes.
- 'Top hat' sections with cold bridge tape.
- Profiled, interlocking steel liner trays, usually hot dipped galvanised and coated on the inside face with a white pre-painted PVC finish. The upper surface should be either weather coated or corrosion resistant, to withstand the effects of interstitial condensation.
- Quilt insulation laid between the external sheets and in the troughs of the liner trays.

Advantages

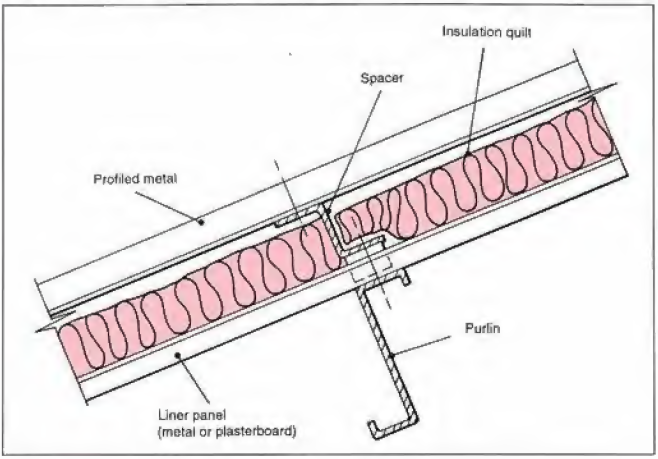
- Liner trays are generally capable of spanning greater distances than liner panels, which are typically restricted to spans of 2.0m or less. This can reduce the amount of steelwork needed.
- Liner trays are resistant to site damage and give an attractive interior finish, which is easily cleaned.
- Liner trays provide a drainage path for any condensate that may form within the construction.

Disadvantages

- In this application (unlike in a wall situation), the system requires the liner tray to span parallel to the weather sheeting. Consequently, the arrangement needs to include an additional element to act as a counter batten. This usually takes the form of a 'top-hat' section running across the top flanges of the liner trays. A cold bridge insulant is required between this and the outer sheeting.

- The joints between trays should be sealed against vapour ingress.
- The system compares unfavourably in terms of cost. Material costs are typically 40-50% more expensive than a liner *panel* system.
- There is a risk of condensation occurring within the construction which could:
  - saturate the insulation and reduce its efficiency
  - corrode the liner from within
  - drip through the liner.
- Possibility of quilt insulation being omitted from areas of cladding, thereby reducing the overall performance.

5.2.2 Profiled metal sheet + insulant + metal liner panel system



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam or concealed-fix systems, coated with a range of high quality, colour protective finishes.
- Metal spacer systems with thermal break.
- Profiled interlocking steel liner panels, typically coated with a protective enamel finish.
- Quilt insulation laid between the external sheets and liner panels and cut to fit tightly between the metal spacers. All quilt edges butted tightly.

Advantages

- The metal liner panels are quick to install and resistant to site damage, and give an attractive interior finish that is easily cleaned.
- Generally cheaper than composite panel systems.

Disadvantages

- Some spacer sections can block the drainage path down the liner panels, leading to a build-up of condensate within the construction. Careful selection of the spacers used, can avoid this occurrence.

- With quilt insulation there is a risk of condensation forming within construction which could:

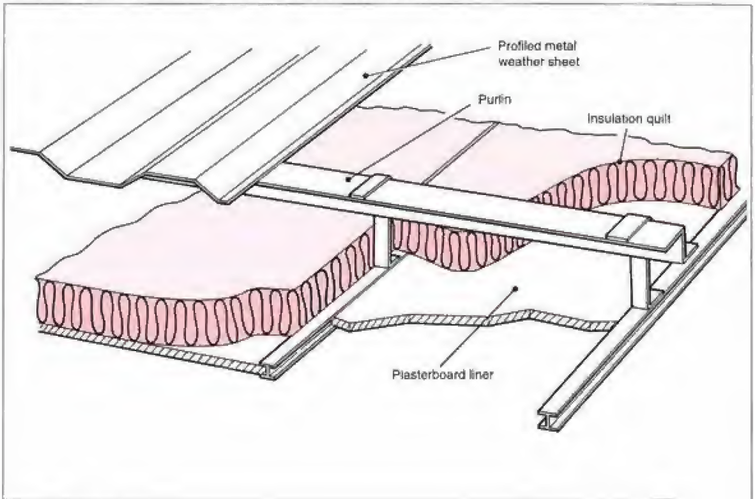
    cause mould growth

    corrode the liner from within

    drip through the liner.

- Possibility of quilt insulation being omitted from areas of cladding, thereby reducing overall thermal performance.

5.2.3 Profiled metal sheet + insulant + plasterboard lining system



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam and concealed-fix systems, coated with a range of high quality, colour protective finishes.

- Treated softwood timber or galvanised-steel spacer battens.

- Plasterboard lining panels, foil backed white PVC-faced, supported in white stoved galvanised steel over-purlin fixing system.

- Quilt insulation laid between the external sheets and plasterboard lining panels, cut to fit tightly between the spacer battens. All quilt edges butted tightly.

- Insulation values: see Table below

Mineral wool thickness (mm)	Approx U-value (W/m^2K)	Relative material cost *
60	0.46	100
75	0.39	104
100	0.30	117

* 60 mm insulation = 100

Advantages

- Roofing system used quite successfully over many years
- Economical in use
- Easy to handle and install.

Disadvantages

- Interstitial condensation has particularly serious consequences with this type of construction. In addition to the saturation of the quilt insulation, resulting in loss of efficiency, the moisture can also waterlog the plasterboard liner, causing staining, leaks, and ultimately, serious damage to the liner.

- Problem of laying the quilt and keeping it dry in adverse weather conditions.

- Softwood timber spacer battens used with this system could have a high moisture content when first laid. In drying out, shrinkage could loosen fixings and induce leaking.

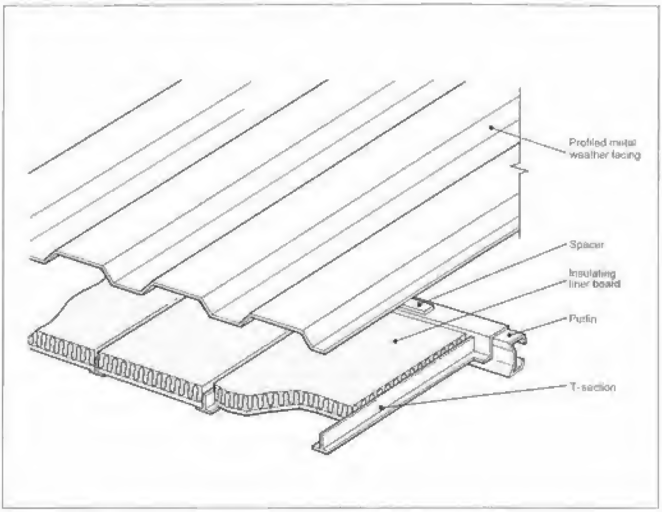
- Timber battens will rarely be completely straight and there is a possibility of fasteners missing the battens altogether.

- Possibility of quilt insulation being omitted from areas of cladding, thereby reducing overall thermal performance.

- Lifespan of plasterboard.

- Process limitation: the absorbent nature of the liner can preclude some activities or industrial processes.

5.2.4 Profiled metal sheet + insulating liner board system



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam and concealed-fix systems, coated with a range of high quality, colour protective finishes.

- Rigid lightweight closed cell insulation liner board, aluminium faced on both sides, supported in metal T-section or H-section under- or over-purlin fixing system, with all joints taped. Alternatively, rigid mineral wool panels are available which include a decorative, washable PVC facing.

  The type and thickness of insulation can be chosen to match the performance required: see Table below.

Closed cell foam thickness (mm)	Approx total U-value (W/m^2K)	Relative material cost (complete sandwich)*
40	0.48	100
50	0.40	106
60	0.34	114
Mineral wool thickness (mm)		
50	0.49	100
75	0.35	110
100	0.28	127

* 40 mm thickness = 100

Advantages

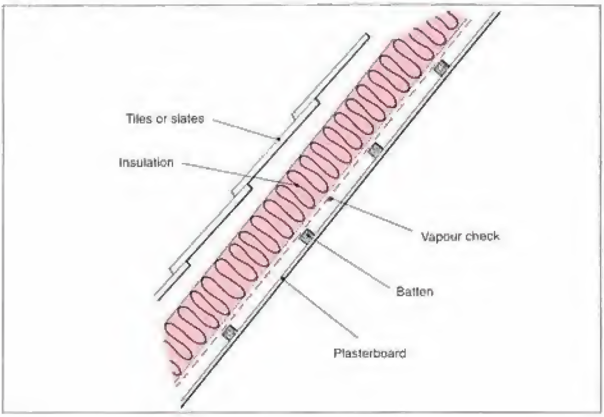
- Insulating liner boards are light, easy to handle and install and have a built-in vapour barrier over the foil or PVC covered surfaces.

Disadvantages

- Requirement that all board joints are taped on the reverse side to help reduce cold bridging, and prevent the ingress of vapour that may condense above the insulation.

- It is not always possible to ensure that full continuity of the vapour barrier is achieved; the use of this type of cladding should be confined to low-humidity applications, or where water vapour is removed from the air by other means.

5.3 Tiles or slates



Description

A roof incorporating tile or slate construction would generally be limited to small factory units with a minimum roof slope of 20°, depending on exposure grading and wind loading.

- Tiles: wide range of interlocking or plain tiles, manufactured from concrete or clay.

- Slates: wide range of slates manufactured from concrete, slate or fibre-reinforced cement materials.

- Fixed to treated timber battens.

- Underlay and insulation on profiled steel sheeting or plasterboard with timber counter battens.

Insulant thickness (mm)	Approx U-value (W/m^2K)	Relative material cost
50	0.46	100
75	0.34	110
100	0.27	129

* 50 mm thickness = 100

Advantages

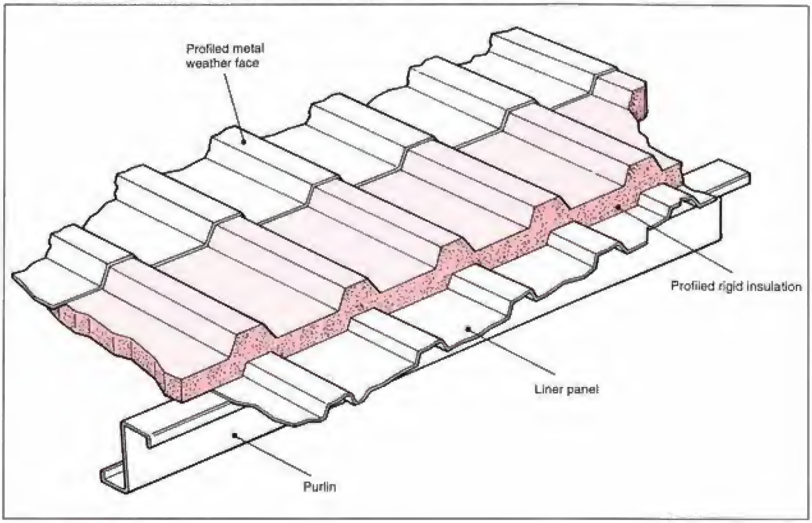
- External aspect that can blend with regional building styles.
- Clean, maintenance free internal surface.

Disadvantages

- Requires steeper roof slopes than metal cladding that will limit application to small span buildings.
- Possibility of quilt insulation being omitted, thereby reducing overall thermal performance.

Note: Profiled steel weather faces are available which simulate a tile effect and may be used on pitches lower than 20°.

5.4 Site-assembled composite panel (also applicable to walls)



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam systems, coated with a range of high quality, colour protective finishes.
- Profiled rigid insulation boards occupying the space between the external sheets and liner panels, usually of polyurethane, polystyrene, or mineral wool.
- Profiled metal liner panels, typically coated with a protective enamel finish.

Insulant thickness (mm)	Approx U-value (W/m^2K)	Relative material cost *
40	0.48	100
50	0.40	106
60	0.34	114

* 40 mm thickness = 100

Advantages

- The system is quick to install and any areas damaged on site during construction can be relatively easily replaced.

- Materials generally not affected by bad weather during construction.

- The rigid insulation supports the outer sheets, eliminating the need for metal supports or battens, cold bridging tapes, etc, making it virtually impossible to omit panels of insulation.

- Profile fit of insulation eliminates cold spots and ingress of vapour. Therefore, interstitial condensation can be avoided, provided a good match-up can be achieved on-site. It is generally not possible to avoid some small voids occurring at side and end laps of sheeting, however, and it is therefore advisable to include seals in the laps of liner sheets to create an effectively continuous vapour barrier.

- The way the components fit together makes it virtually impossible for insulation boards to be omitted and hence the design U-value is always assured.

- Additional costs may be offset by reduced need for validation because of confidence in as-built standard of insulation.

- Use of mineral wool insulants gives improved fire resistance compared with composite panels using foam insulation.

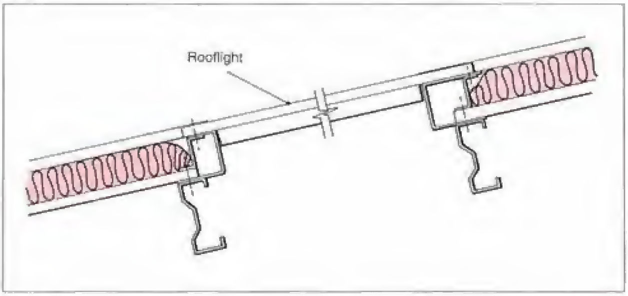
Disadvantages

- The system is not truly 'composite' since no structural composite action can take place (because the elements are not bonded together). Consequently, the system cannot achieve the same spanning capacities as a factory-bonded panel.

- Generally, this type of construction is more costly than other forms of site-assembled systems.

- With the use of foam insulants, fire resistance is generally poor.

5.5 Rooflights



Description

- A range of rooflights is available to match the type of profiled roof cladding chosen for a particular building, and to satisfy requirements for daylighting, weathertightness and thermal efficiency.

- Typically, these would be either double-skin site-assembled or double-skin factory-assembled sealed units, comprising a weather sheet with profile to match the main roof cladding and a lining panel separated with a specified still air space between.

- The sheets are manufactured from glass-fibre reinforced polyester resins or PVC resins, containing uv inhibitors, fire retardants and processing additives.

- Natural translucent double-skin units permit admission of diffused daylight in excess of 65%.

- Rooflights cannot be assumed to have the span capabilities comparable with the roofing materials in conjunction with which they are used. Technical advice should be obtained on the capabilities of a particular weather sheet profile for given purlin spacing and wind load factor.

- In order to satisfy the requirements for daylighting, weathertightness, ease of fitting and thermal efficiency, rooflight layout pattern should be selected in descending order of desirability of:

  ridge to eaves

  partway down slope to eaves

  scatter or chequerboard pattern

  continuous runs across roof slopes.

- It is most desirable to run site-assembled rooflights into the eaves or valley so that any condensate which forms within the air-space can run directly into the guttering. In order to achieve this, it is essential that any spacers included in the system are perforated or otherwise to enable water to drain down the slope to the gutter.

- U-values in the region of 2.9 W/m^2K.

Advantages

- Effective means of combining reasonable thermal insulation values and daylight levels in buildings.

- Double-skin, factory-assembled sealed units are manufactured in a controlled environment, ensuring that high standards of quality are maintained in the completed rooflights, and reducing the potential problems of dust entrapment and interstitial condensation.

- Installing a single pre-fabricated finished component is more efficient and cost effective and aids fast completion of the building envelope.

Disadvantages

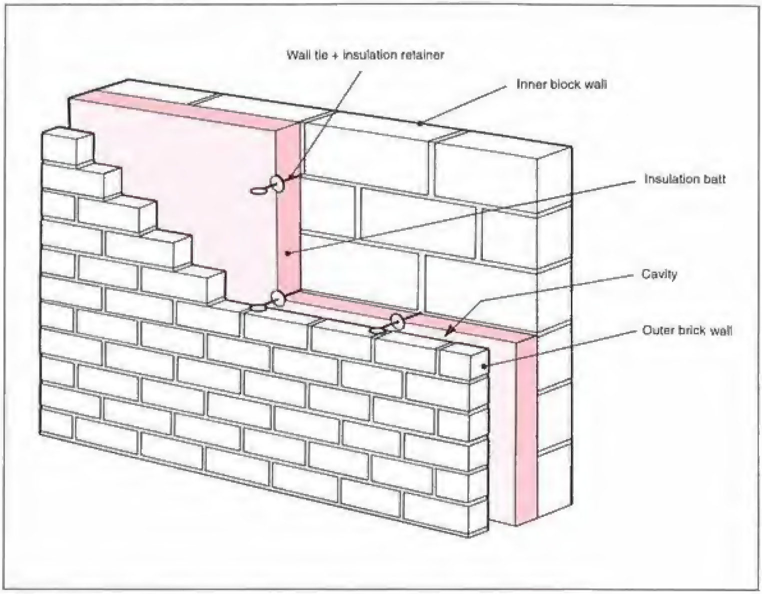
- Double-skin, site-assembled rooflights require a high standard of installation and close supervision to be effective. Where site conditions are less than favourable, or the level of skill for installation is lacking, it is frequently found that site-assembled units are incorrectly fitted, with danger of dirt and moisture ingress and lack of insulating performance.

- Rooflight areas should be chosen with care so that good daylighting is achieved without excessive heat loss and solar gain. The *CIBSE Applications Manual: Window design*[13] and *BRE Information Papers*[9,10] give details. Effective lighting controls are needed if the energy benefits of daylighting are to be achieved, and regular cleaning of rooflights will also be required.

6 Wall construction

Refer to Section 5.1 for **Factory-bonded composite panel wall construction.**

6.1 Masonry cavity walling



Description

There is a wide range of constructions that can meet the structural standards and minimum transmittance U-value requirements.

- Typical construction for an AFU is:

  external leaf: facing brick - clay or concrete

  cavity insulation:

  (a) partial fill + 50mm clear cavity:
  semi-rigid slab or batt.
  bonded to inner block leaf

  (b) total fill:
  semi-rigid slab or batt

  internal leaf: blockwork which may be of light, medium-weight, or dense concrete. If of the porous type, a heavy bodied air barrier paint should be applied to control air leakage through the block.

- Insulation values vary with material specification and element thickness, but can be summarised as follows:

  Brick /cavity /medium weight block + insulant (mineral fibre, glass fibre, or expanded polystyrene slab): see Table on Page A27.

Insulant thickness (mm)	Approx U-value (W/m^2K)	Relative cost *
50	0.46	100
75	0.35	103
100	0.28	109

* 50 mm thickness = 100

Brick/cavity/lightweight block + insulant: see Table below.

Insulant thickness (mm)	Approx U-value (W/m^2K)	Relative cost *
30	0.47	100
50	0.37	104
75	0.29	108

* 50 mm thickness = 100

Advantages

- Thermal response period (being longer than for sheet constructions) can reduce occurrence of overheating in summer.
- Excellent durability.
- High degree of fire protection, thermal and sound insulation automatically provided.
- Resistant to damage (but see below for lightweight concrete blocks).
- Maintenance costs minimal.
- Flexible in application.
- Aesthetically pleasing.

Disadvantages

- May increase construction time and costs.
- Large areas of masonry walling will lead to a substantially slower thermal response for the building as a whole. This may be critical if the building is heated on an intermittent basis.

Problem areas

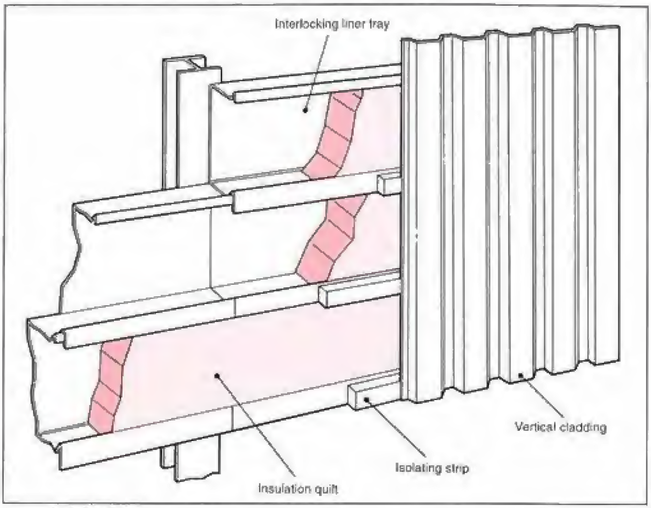
The main risks are:

- Rain penetration if not properly constructed and under certain conditions of driving rain.
- Possible cold bridging and condensation at openings and junctions with internal walls and floors.
- The use of lightweight aerated concrete blocks to achieve high standards of insulation is not always compatible with the degree of wear and tear to which these will be subjected. Consequently, the use of denser blocks is frequently required, which necessitates the use of additional insulation within the cavity.

These and other potential technical risks are explained in detail, and recommended avoiding actions are given in the BRE Report *Thermal insulation: avoiding risks*[5].

6.2 Profiled metal sheet + insulant + liner (site-assembled)

6.2.1 Profiled metal sheet + insulant + liner tray system



Description

- Profiled metal external sheets (steel or aluminium), including standing seam or concealed-fix systems, coated with a range of high quality, colour protective finishes.
- Profiled interlocking steel liner trays, hot dipped galvanised and coated on the inside face with white pre-painted PVC finish.
- Quilt insulation laid between the external sheets and in the troughs of the liner tray. Refer to Section 5.2 for insulation values.

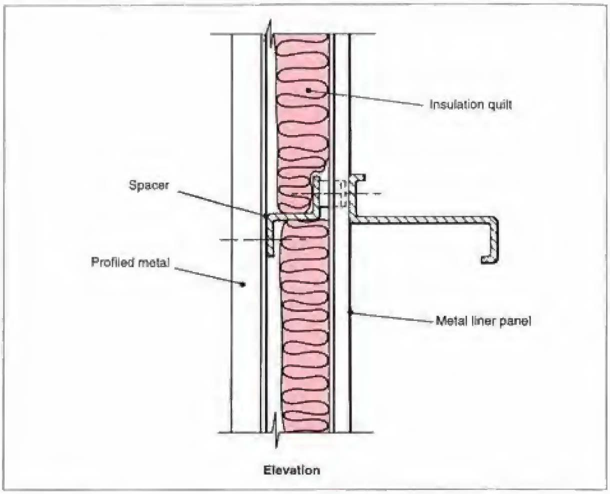
Advantages

- Steel liner trays are essentially structural elements which eliminate the need for sheeting rails within certain span limitations.
- The absence of sheeting rails leads to a clean and aesthetically pleasing internal surface.
- The elimination of sheeting rails from the construction leads to faster erection times with earlier completion of the building envelope.

Disadvantages

- Difficulty in achieving acceptable standard of insulation installation. Both cold spots, and a degradation of U-values occur if the quilt is not kept in place, or sags, either during or after installation. This imposes a requirement for a high level of supervision to maintain build quality.
- Difficulty in achieving good seal between trays to prevent air leakage.
- In the case of steel portal frame construction, it is frequently necessary to provide some form of lateral restraint to the inner flange of the stanchion at high level. A convenient method is to fix diagonal straps between the flange and a nearby sheeting rail. Therefore, eliminating the sheeting rail necessitates the provision of an alternative means of restraint.

6.2.2 Profiled metal sheet + insulant + liner panel system



Description

- Profiled metal external sheets (steel or aluminium), including standing-seam or concealed-fix systems, coated with a range of high quality, colour protective finishes.
- Metal spacer system with thermal break.
- Profiled metal liner panels, typically coated with a protective enamel finish.
- Quilt insulation laid between the external sheets and liner panels and cut to fit tightly between the metal spacers, or sandwiched tightly between rails and sheets, so that insulation is compressed locally. All quilt edges are butted tightly. Alternatively, rigid board insulation may be used so that sheeting is fixed through the batts directly into the rails, obviating the need for metal spacers. Refer to Section 5.2 for insulation values.

Advantages

- A widely-used versatile system which is economical and quick to install. An attractive, easy to clean internal finish is provided.

Disadvantages

- Quilt insulation is vulnerable to wet conditions during construction and performance can be drastically altered if it is allowed to become saturated.
- Possibility of insulation being omitted or sagging following installation, thereby reducing overall thermal efficiency.
- The presence of an unvented cavity within the construction can lead to a build-up of condensate which could:

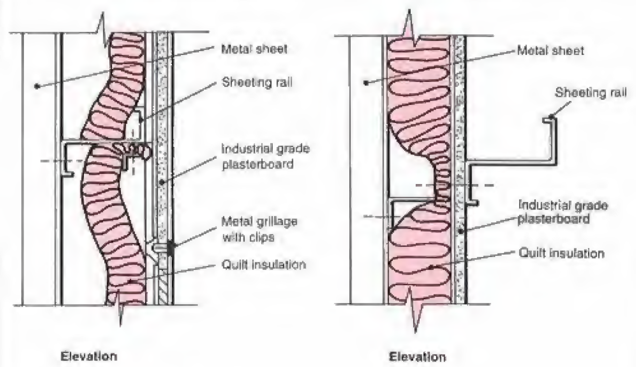
  saturate the insulation and reduce efficiency

  cause mould growth

  corrode the liner/rails from within.

Where long spans are used, or in high-humidity conditions, side and end laps of liner panels should be mechanically fixed and sealed, to provide an effective vapour barrier.

6.2.3 Profiled metal sheet + insulant + plasterboard lining system



Alternative Plasterboard Lining Systems

Description

- Profiled metal external sheets (steel or aluminium), coated with a range of high quality, colour protective finishes.
- Industrial grade foil-backed plasterboard lining panels, usually fitted into a grid of light metal sections and clips, spaced off the integral face of sheeting rails, or fixed to the outer face of the sheeting rail. In the latter case, a metal spacer rail is required to separate the two skins.
- Quilt insulation suspended in the cavity and compressed under the spacer rails (if provided). Refer to Section 5.2.3 for U-values.

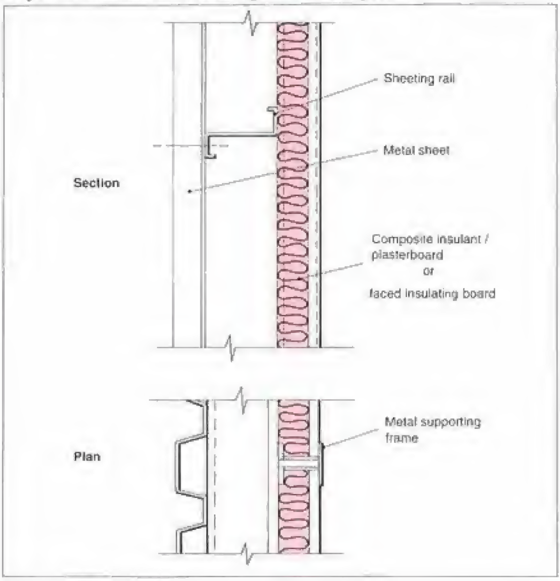
Advantages

- Relatively low costs of installation.
- Wall boards are generally small enough to handle and install easily.
- Damaged areas can be easily replaced if fixed to inside of sheeting rails.
- Appearance suitable for Office Areas.

Disadvantages

- Air penetration during construction and a non-continuous vapour barrier may lead to build-up of condensate within the insulation if this is in contact with the outer sheet.
- Problem of ensuring quilt is not 'stretched' under its own weight. This can be solved by using quilts which are paper-faced.
- Possibility of quilt insulation being omitted from areas of cladding or sagging following construction, thereby reducing overall thermal performance.
- Plasterboard is generally not as durable as steel sheet liners, or dense concrete blockwork, in situations subject to general wear and tear or impact damage.
- Plasterboard fitted on the outer face of sheeting rails, and the insulation, must be fixed prior to installation of the outer sheets, leading to problems in keeping the board and quilt dry in adverse weather conditions. This may be overcome by fitting the board on the inside face of the sheeting rails after the building is weathertight.

6.2.4 Profiled metal sheet + insulating liner board system



Description

- Profiled metal external sheets (steel or aluminium), coated with a range of high quality, colour protective finishes.
- Rigid insulation, comprising a decorative-faced board or a composite plasterboard/ insulant panel, normally fitted into a grid of light metal sections on the inner face of the sheeting rails. The board can include an integral vapour barrier. Refer to Section 5.2.4 for U-values.

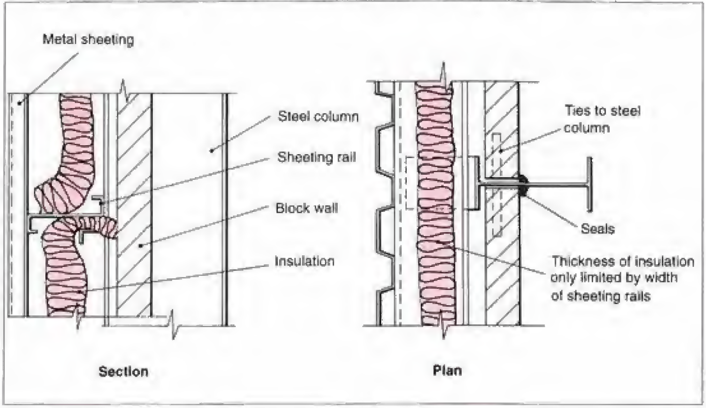
Advantages

- The use of a factory-made composite insulant/facing leads to quicker installation times.
- The rigidity of the board ensures that spacer rails are not required to separate the internal and external facings.
- Damaged areas can easily be replaced, if fixed to the inside of the sheeting rails.
- No possibility of insulation being omitted, since any omission would be self-evident.

Disadvantages

- Interstitial condensation can leak into building as inner skin cannot be sealed.
- Possible problems of durability in areas subject to wear and tear.
- If the insulating board is fixed to the outer face of the sheeting rail, it will be exposed to the weather during construction, since in this case the external sheeting must be fixed after the insulating board.

6.3 Blockwork inner lining + steel sheet with insulation or composite panel cladding



Description

- A system normally used to provide a hard-wearing internal surface at lower levels within the AFU or to provide a surface more appropriate to any Office Area which may be present.
- Since the block normally needs to be hard-wearing, the medium-to-dense range of blocks is more appropriate than the lighter weight units. Blockwork and metal cladding alone will not provide sufficient insulation to satisfy the requirements of Building Regulations and consequently additional insulants are required. Porous blockwork should be painted to prevent air infiltration through the wall. Therefore, the construction can consist of a broad range of cladding and insulating elements, as outlined in Section 5. The blockwork tends to act as a substitute for the sheet or board liners, albeit with somewhat better insulating values.
- The gap between inner blockwork wall and columns should be sealed.

Advantages

- The choice of this lining construction is dictated by criteria other than thermal efficiency. Once this option is selected, it is possible to install thicknesses of insulation which give U-values lower than statutory requirements at little extra cost, as shown below.

  Typical U-values and cost analysis for steel weather sheet, quilt insulation between purlins, blockwork lining: see Table below.

Quilt insulation thickness (mm)	Approx U-value (W/m^2K)	Relative material cost *
80	0.42	100
100	0.35	104
150	0.24	115
200	0.18	120

* 80 mm thickness = 100

Disadvantages

- Speed of construction may be reduced due to presence of blockwork, particularly if blockwork needs to be installed before sheet cladding.

- Rigid or semi-rigid batts, if used, may need to be fixed to the face of blockwork, before the installation of sheet cladding. Hence, cladding operations may be delayed for blockwork and insulation to be installed beforehand. Also, insulation of this type will be exposed to the weather during construction. The use of quilt insulation can overcome these problems, because it can be installed behind the sheet cladding in dry conditions, prior to construction of the blockwork liner. Note that the type of insulant selected must be compatible with the system used above the level of the blockwork liner.

- Possibility of insulation being omitted, or sagging following installation, thereby reducing the overall efficiency.

6.4 Goods doors

Description

- Options available are:

  up and overhead sliding insulated sectional doors

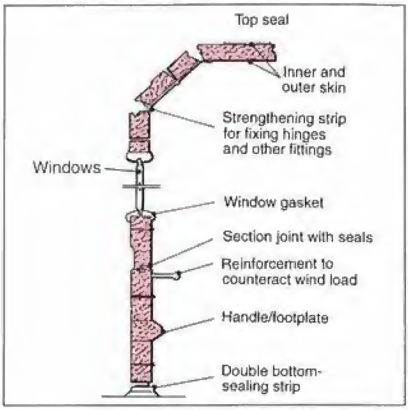
  horizontal side folding insulated shutter doors

  roller shutter doors.

- As a general rule it is most desirable to have these doors open for as short a time as possible[17,18]. Prompt closing of the door after use can be encouraged by incorporating motorised operations and man-doors at the design stage.

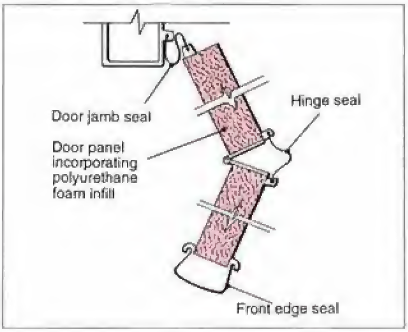
- It is of little value to have a well insulated door which is not well sealed into its structural opening; therefore, it is essential to provide details at top, bottom and sides of the opening which will enable the door to be well fitted and sealed against the external environment. Furthermore, the benefits of installing the door at an earlier stage should be evaluated; in this case the building envelope would be built up to the door frame itself, thereby ensuring that the frame/wall junction matches the required detail.

Up and overhead sliding insulated sectional doors



- Fabricated from panel sections of double-skin aluminium or galvanised steel sheet, with infill of polyurethane foam, and available in a choice of finishes and colours.
- Doors are supplied made-to-measure to suit individual building requirements, and run in a guide track which includes a balancing shaft with rotating springs which compensate for the door weight.
- The edges of the door panels are profiled to form an interlocking, fully weathered, panel-to-panel joint, with seals to prevent edge leakage. Both top and bottom edge trims should be fitted with weather seals.
- Double-glazed window panels can be incorporated in the door panels.
- Doors can be manually or power operated.
- When fully open, the door lies completely above the top edge of the opening.
- Typical U-values are 0.45-0.50 W/m^{2}K.

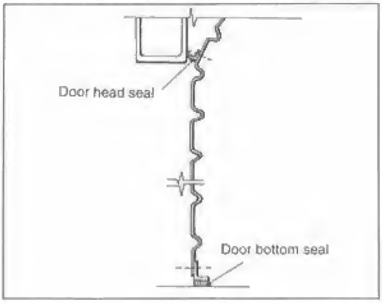
Horizontal side folding insulated shutter doors



- Fabricated from panel sections of plastisol-coated steel sandwich construction, with infill of polyurethane foam, and available in a choice of colours.
- Doors are supplied made-to-measure to suit individual building requirements, supported by an overhead track and, normally, with a bottom guide track.

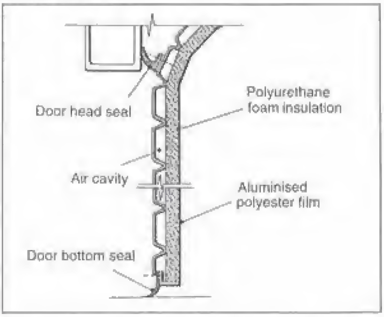
- Double-glazed window panels can also be incorporated in the door panels.
- The edges of the door panels are fitted with seals to prevent air leakage and heat loss when the doors are closed. Top and bottom edge trims should be fitted with rubber or brush weather seals.
- Doors can be manually or power operated.
- Typical U-values are 0.45-0.50 W/m^{2}K.

Roller shutter doors (uninsulated)



- Manufactured from sections of pressed galvanised steel sheet to form a continuous curtain, which rolls to the top of the opening to provide maximum clearance. Available in a choice of finishes and colours.
- Doors supplied made-to-measure to suit individual building requirements, supported by overhead brackets and run in channel side guides.
- Doors can be manually or power operated.
- Large heat losses and condensation can be expected if used in a heated building.
- Typical U-values are 5-6 W/m^{2}K.

Roller shutter doors (insulated)



- Manufactured from pressed galvanised steel sheet with an insulation layer of polyurethane foam, backed by an aluminium polyester film, laminated to the inside of the steel door curtain, which rolls to the top of the opening to provide maximum clearance. Available in a choice of finishes and colours.

- Doors supplied made-to-measure to suit individual building requirements, supported by overhead brackets and run in extra deep channel side guides.

- Doors can be manually or power operated.

- Typical U-values are 0.6-0.7 W/m^{2}K.

6.5 Windows

Description

- Windows would normally be incorporated in the walls of the Office Area, and a wide range of single-glazed and double-glazed windows are available, manufactured with timber, aluminium or uPVC frames, and with or without a durable sub-frame.

- The Building Regulations standards[1] include provisions for simple 'trade-off' options between areas of double-glazing, and wall and roof U-values, allowing several different methods of meeting the overall thermal insulation requirement. This has made it likely that double-glazed windows will be installed more widely in new buildings, as these windows can make a considerable contribution to energy saving.

- Further improvements in thermal insulation can be made by incorporating an additional air space in the window (ie triple-glazing), and/or by including metallic surface coatings of low heat emissivity on the surface(s) of the glass.

- Typical U-values for various glazing configurations: see Table below

Window type	Approx U-value (glazing only) W/m^{2}K
Single-glazing	5.6
Double-glazing	3.0
Triple-glazing	2.1
Double-glazing with surface coating	1.8

- Window sizes and positions need to be chosen with care to allow good daylighting and view out whilst keeping heat losses reasonably low. The *CIBSE Applications Manual: Window design*[13] and *BRE Information Papers*[9,10] give details. For energy efficiency, it is usually best to avoid heavily tinted glazing and instead use clear glazing, possibly in smaller sizes.

- It is important with all window types that the gap between the window frame and window reveal is sealed to prevent air leakage.

Advantages of multiple-glazing

- Considerable contribution to energy saving.
- Reduction in noise pollution.

- The comfort of occupants sitting near windows can be significantly improved by the use of double- or triple-glazing: the surface temperature of the inner face of such a window will be higher than for a single-glazed unit under similar environmental conditions. For example, for internal and external temperatures of 20°C and 0°C respectively, the inside surface temperature of the unit would be approximately as follows:

Single-glazing	6°C
Double-glazing	13°C
Triple-glazing	15°C
Double-glazing with low emissivity surface coatings	16°C.

  Consequently, radiation losses and cold convection currents can be reduced significantly when multiple-glazing is used.

Disadvantages of multiple-glazing

Main risks associated with multiple-glazing are:

- Deterioration of edge seals in multiple-glazed units, leading to condensation within the air space. Using preferred methods and good workmanship for glazing sealed units into the frames is important to reduce the risk of edge seal failure.

Other risks are:

- Partial use of double-glazing may draw attention to condensation on single-glazing: avoid this by specifying complete double-glazing.

7 Floor construction

For most AFU applications, under-slab insulation is not necessary in order to satisfy Building Regulation requirements. In some cases, ie when the building is of small area or unusually narrow in plan, some degree of thermal insulation of the slab will be mandatory in order to achieve a theoretical U-value of 0.45 W/m^2K.

The U-value of a ground-supported concrete slab cannot be calculated easily, unlike the situation with other elements of the building envelope. Not only is it influenced by the materials of construction, but also by the floor's perimeter: area ratio[11], and by the moisture conditions prevailing in the soil beneath the slab. It has been found that heat loss through an uninsulated floor may be doubled if soil conditions change from dry to wet. This effect is greatly reduced if the floor is well insulated.

7.1 Slab on ground

Description

- Granular sub-base laid on a prepared formation.
- Damp-proof membrane.
- Reinforced concrete slab, power-floated, with a suitable arrangement of longitudinal and transverse joints.

Advantages

- Used economically and successfully over a number of years. Provided the slab is well detailed and constructed it can give maintenance-free service for many years.
- Quick and simple to install.

Further guidance on the construction of ground-bearing concrete slabs can be found elsewhere[14].

7.2 Slab on insulant on ground

Description

- Heat losses through a ground-supported concrete slab can be reduced by incorporating an insulant in the construction. In the case of a self-finished slab, this needs to be placed below the slab, on a well-compacted and levelled sub-base. The damp proof membrane (dpm) should be placed below the insulant if moisture is likely to affect the thermal properties of the insulant. It is preferable to place the dpm above an insulation board which is resistant to moisture and contaminants from the ground.

- It is of primary importance that any insulation placed below the floor slab is durable and rigid enough to function satisfactorily throughout the design life of the building.

- Below-slab insulants take the form of rigid board products. These are available in various materials and thicknesses (typically in the range 25-75mm), and are normally butt-jointed together. Some products include a profiled joint. The product types are:

  mineral wool slabs

  expanded or extruded polystyrene slabs.

- After an initial heating period, the majority of the heat lost through a floor slab is via its perimeter. Hence, most of this heat loss can be prevented by using insulation placed around the perimeter only, along with full or partial insulation of a masonry cavity below floor level. This can result in an economical form of insulation which effectively eliminates the cold bridge at the perimeter and the associated surface condensation risk.

Advantages

- Incorporation of insulation below a floor slab leads to:

  reduced heat loss

  greater comfort (by increasing the surface temperature of the floor)

  reduced risk of surface condensation.

- Particular attention paid to insulating the slab perimeter can reduce the effects of cold bridging which occur in this area.

- The greatest advantage is gained when the building is to be constantly heated. This is because advantage can then be taken of the thermal capacity of the ground slab. The slab, however, would take a long time to 'warm up' and consequently this benefit cannot be exploited if the building is heated on an intermittent basis.

Disadvantages

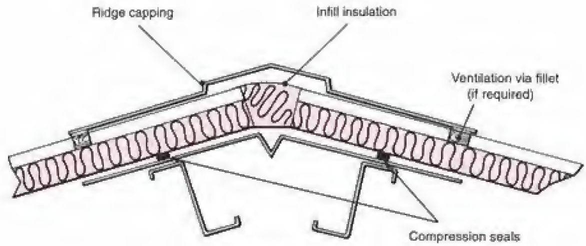
- Insulating materials may lose thermal resistance if subject to high compressive strain, water absorption or contamination. These problems can be avoided by careful material selection.

- The construction process requires additional precautions to protect the board and dpm before and during concreting.

8 Junction details

It is not the intention of this Section to provide a set of 'standard' details for given forms of construction, but rather to indicate the problem areas which exist when different materials and components meet. It is not always possible to satisfy fully all requirements of a particular detail but, it is hoped that the following paragraphs will stimulate the designer to give full consideration to all the criteria involved.

8.1 Ridge details

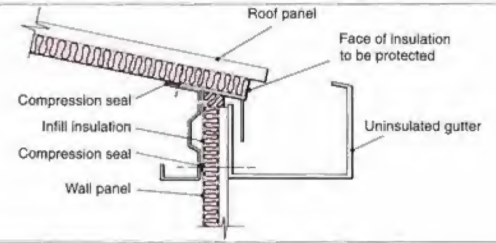


Typical Ridge Detail

- Establish from the outset whether or not the roof construction requires ventilation at the ridge.
- Provide continuous insulation across the ridge.
- Check on the degree of movement expected in the metal facing and liner, and allow for this if necessary in the closure strips.

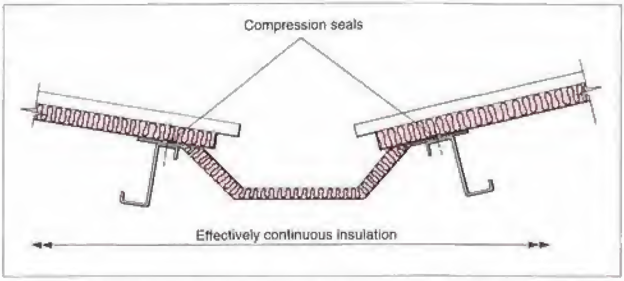
8.2 Eaves and gutter details

8.2.1 Composite panel in roof and wall



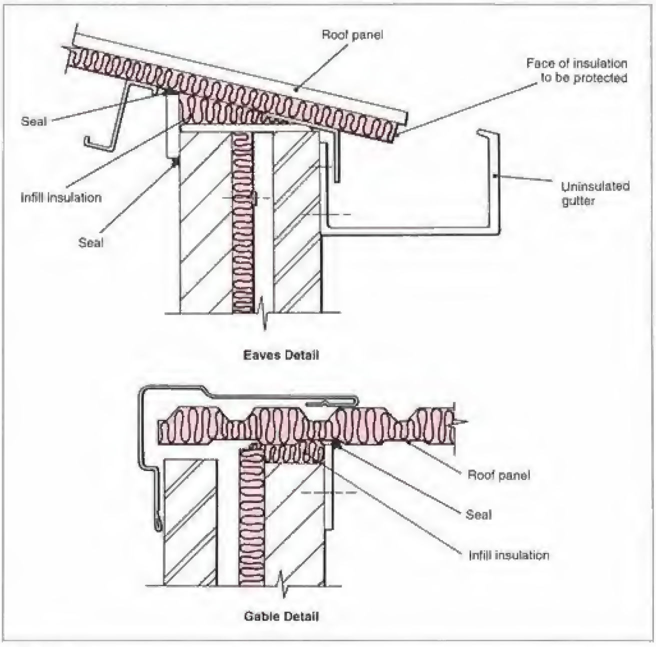
- Unlike site-assembled systems incorporating air gaps, there is no requirement for eaves or ridge ventilation *per se*.
- Ensure insulant at exposed ends of sheets is covered to avoid degradation.
- The risk of water penetration into the building can be reduced by locating guttering outside the sheeting face.

- Internal gutters (eg behind parapets or in valleys) must be insulated. Ensure insulation is effectively continuous with main roof and wall insulation.



- All internal downpipes should be insulated to prevent condensation forming on and running down the cold surface.
- If parapets are to be insulated, ensure coping sheets are insulated also
- If parapets are insulated, ensure insulation and vapour barrier are continuous below the parapet.

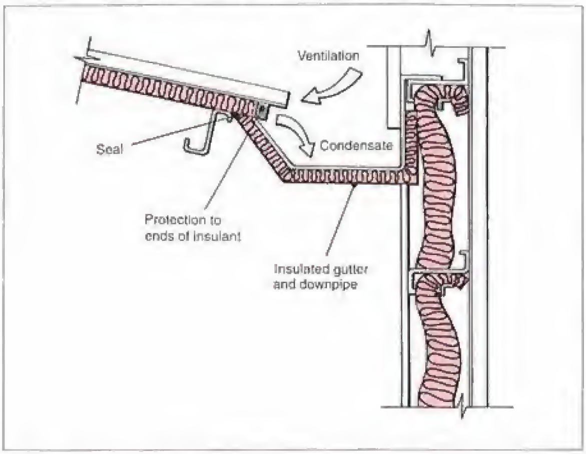
8.2.2 *Roof: factory-bonded or site-assembled composite panel* *Wall: masonry cavity walling*



Description

- Unlike site-assembled roof systems incorporating air gaps, there is no requirement for eaves or ridge ventilation *per se*.
- Ensure insulant at exposed ends of sheets is covered to avoid degradation.

8.2.3 *Roof: profiled metal sheet + insulant + liner (site-assembled)* *Wall: profiled metal sheet + insulant + liner (site-assembled)*



- It is difficult to achieve an effectively continuous vapour barrier with many of these systems and consequently the air space which is present needs to be ventilated.

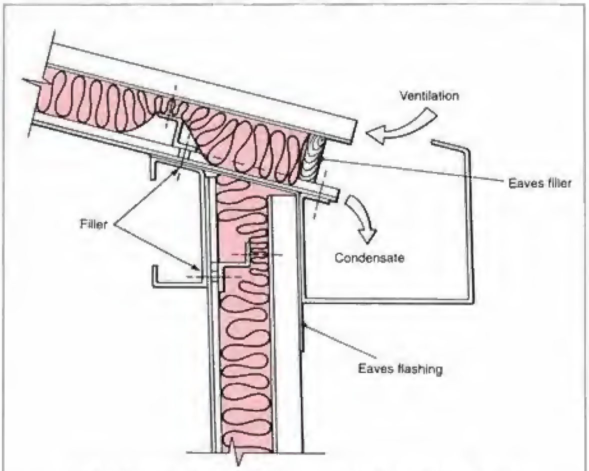
- The ventilated air space requires:

  air entry along the eaves

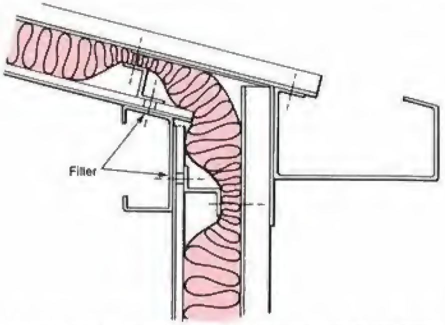
  free air passage between insulation and metal sheeting between eaves and ridge

  air exit along the ridge.

- The condensation risk needs to be assessed and, if this is significant, the whole roof construction, including the eaves detail, must be designed so that any accumulations of water can be disposed of to the guttering (see Detail A). This will almost certainly lead to a cold bridge occurring through the liner sheet at the eaves.

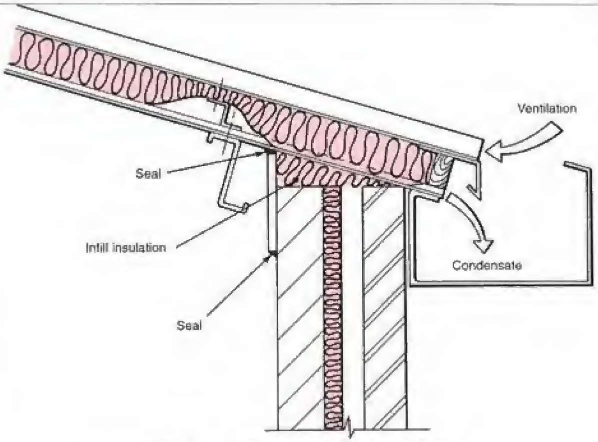


DETAIL A: Provides Drainage Path for Condensate but No Continuity of Insulation

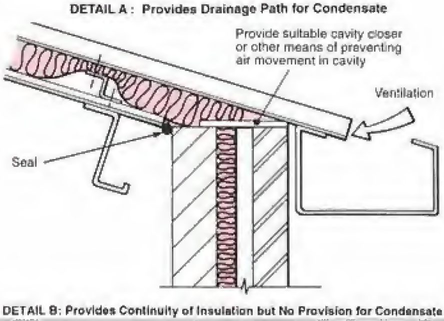


DETAIL B: Provides Continuous Insulation but No Provision for Condensate

8.2.4 Roof: profiled metal sheet + insulant + liner (site-assembled)
Wall: masonry cavity wall



DETAIL A : Provides Drainage Path for Condensate

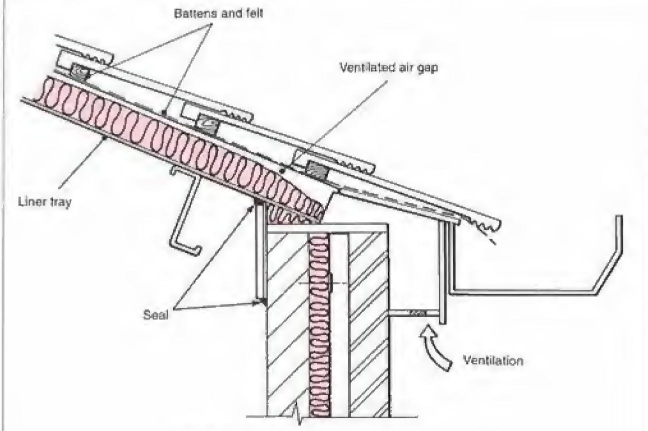


DETAIL B: Provides Continuity of Insulation but No Provision for Condensate

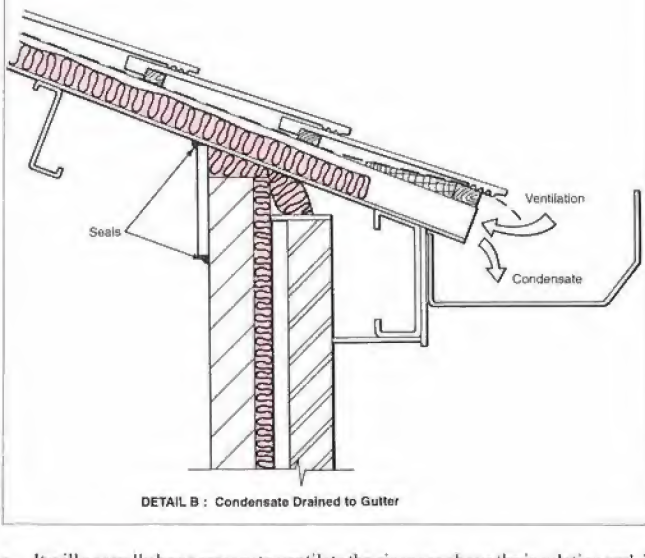
See Section 8.2.3 for general comments on roof construction.

- As a general rule, allow for ventilation at eaves and ridge and provide continuity of insulation as far as practicable.

8.2.5 *Roof: tiles or slates*
Wall: masonry cavity wall



DETAIL A : No Drainage of Condensate



DETAIL B : Condensate Drained to Gutter

- It will normally be necessary to ventilate the air space above the insulation and, if condensation is expected to occur in significant quantities, to provide a drainage path to the guttering.
- If a condensate drainage path is not deemed necessary it will be easier to provide continuity of insulation around the eaves, thereby avoiding cold bridging.

Note: Other wall options are possible, but are rarely encountered, and hence are not considered here.

8.3 Stub wall/cladding details

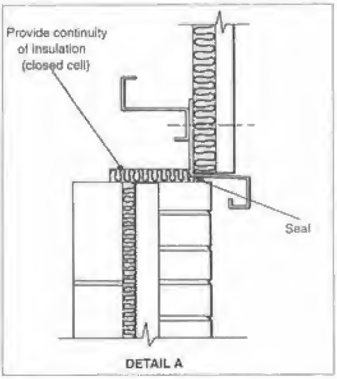
8.3.1 Insulated composite panel/masonry wall

- This junction is an area particularly prone to uncontrolled infiltration.

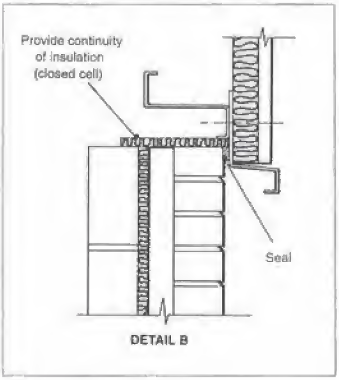
- Two options are generally available at this detail.

  Detail A: The face of the panel is less than a panel thickness in front of the brick face and consequently the panel stops short of the cavity wall.

  Detail B: The panel is proud of the brick face and can therefore run down past the top of the masonry.



With Detail A the weather seal has to be made above the top brick and tends to be subjected to greater shear stresses and exposure than when Detail B is employed.



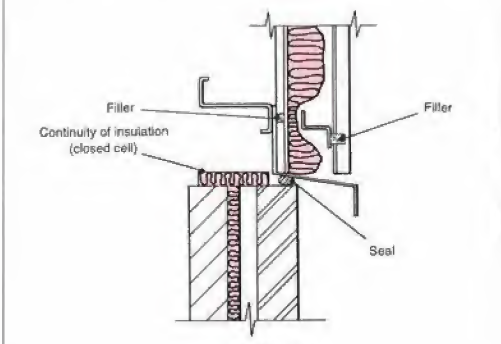
Detail B has to be specified so that brickwork tolerances can be accommodated. The brick face is *not* a straightline; the irregularities in the brick unit, the perpend joints, and the out-of trueness of the wall itself must be allowed for when detailing the seal and setting the steelwork/walling relationship. There is also a danger that, under wind suction, the panel may pull away from the brick face and open the seal.

8.3.2 Profiled metal sheet + insulant + liner (site-assembled)/masonry cavity walling

- This junction is an area particularly prone to uncontrolled infiltration.

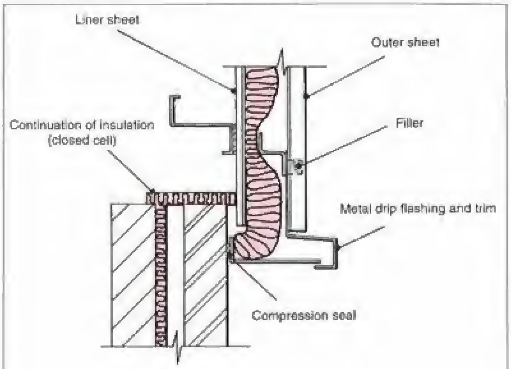
- Two options are generally available at this detail.

  Detail A: The internal face of the liner is set behind the outer face of the cavity wall. Consequently, the site-assembled sandwich construction stops short of the cavity wall.



DETAIL A

  Detail B: The liner is able to run down in front of the outer face of the cavity wall.



DETAIL B

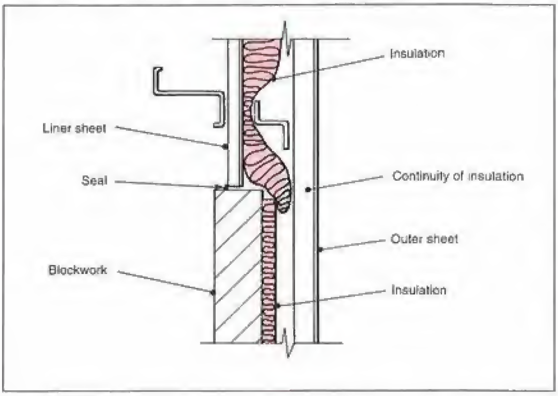
- Within these, many differing detail arrangements are possible at this junction, two of which are indicated above. Criteria which need to be satisfied are:

  avoidance of cold areas on the liner face (difficult to achieve on Detail A)

  avoidance of free air-flow between the masonry and the sheeting.

Refer also to Section 8.3.1 for notes on weather seals.

8.3.3 Profiled metal sheet + insulant + liner (site-assembled)/blockwork inner liner + metal sheet/composite panel cladding

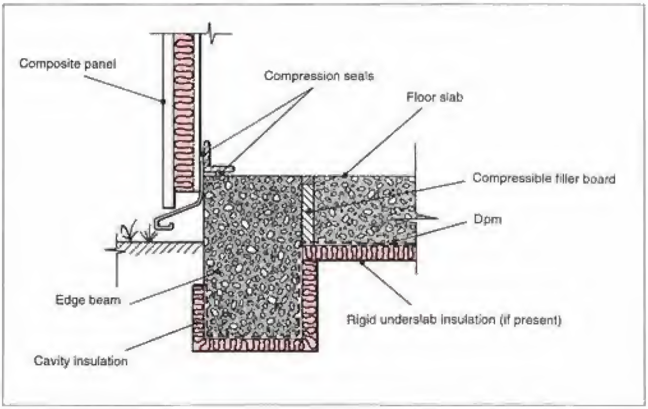


- In this form of construction the outer metal sheet can run down part of the block wall thereby ensuring that no infiltration can take place at this point.

- The type of insulation may change at the top-of-blockwork level and here the continuity of insulation should be ensured by means of a suitable overlap.

8.4 Wall/floor details

8.4.1 Profiled metal sheet + liner + insulant, or composite panel, factory-bonded, or composite panel, site assembled.

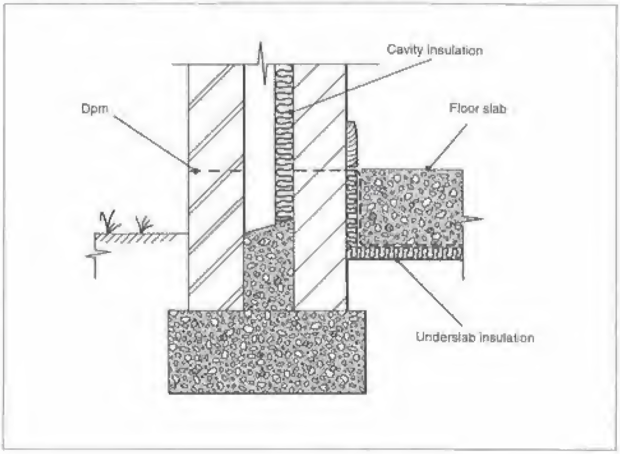


- By continuing the insulation around the edge beam, cold bridges can be avoided.

- An effective seal may be made at the bottom fixing of the lining/panel, thereby preventing uncontrolled infiltration.

8.4.2 Masonry cavity walling.

- Cold bridging at the floor perimeters can be reduced by placing a strip of underslab insulation around the slab margins. It can be effectively eliminated by the addition of further insulation board placed vertically at the slab/wall junction as shown below. If the dpm is located on the concrete side of the board it will need to be protected at the surface by suitable means, eg a skirting board.



9 References and further information

9.1 Statutory regulations

1 **Department of the Environment and the Welsh Office.** *The Building Regulations Approved Document Part L: Conservation fuel and power.* 1990.
or **The Scottish Office.** *Technical Standards, For Compliance with the Building Standards (Scotland) Regulations Part J : Conservation fuel and power.* Edinburgh, HMSO, 1990.
or **Department of the Environment For Northern Ireland.** *The Building Regulations (Northern Ireland) 1990. Technical Booklet F : Conservation fuel and power.* Belfast, HMSO, 1992.

9.2 Guidance publications - general

2 **British Standards Institution.** British Standard Code of practice for energy efficiency in buildings. *British Standard* BS8207: 1985. London, BSI, 1985. Available from HMSO bookshops.

3 **Deacon R C.** Concrete ground floors: their design, construction and finish. *Cement and Concrete Association Publication* 48.034. Wexham Springs, Slough, C & CA, 1976, 2nd edition.

4 **Chandler J W E and Neal F R.** The design of ground supported concrete industrial floor slabs. *British Cement Association (BCA) Interim Technical Note* 11, Wexham Springs, Slough, BCA, 1988.

5 **Building Research Establishment.** Thermal insulation: avoiding risks. *BRE Report* 143. Garston, BRE, 1989. BRE, Garston, Watford, WD2 7JR; tel 0923 664444; fax 0923 664010.

6 **O'Reilly J J N.** Better briefing means better buildings. *Building Research Establishment Report* BR95. Garston, BRE, 1987.

7 **Building Research Establishment.** Climate and site development, Pts 1-3. *BRE Digest* 350. Garston, BRE, 1990.

8 **Hughes D.** Energy efficient factories: design and performance. *Building Research Establishment Information Paper* IP 13/89. Garston, BRE, 1989.

9 **Littlefair P J.** Average daylight factor: a simple basis for daylight design. *Building Research Establishment Information Paper* IP 15/88. Garston, BRE, 1988.

10 **Littlefair P J.** Site layout planning for daylight and sunlight: a guide to good practice. *Building Research Establishment Report* 209. Garston, BRE, 1991.

11 **Anderson B R.** The U-value of ground floors: an application to building regulations. *Building Research Establishment Information Paper* IP 3/90. Garston, BRE, 1990.

12 **Eurisol UK Limited (UK Mineral Wool Association),** 39 High Street, Redbourn, Herts AL3 7LW; tel 058 285 4624; fax 058 285 4300.

(a) Design manual for the insulation of building structures, 1986.

(b) U-value guide, 1988.

(c) The Eurisol guide to the new thermal insulation standards using mineral wool, 1989.

(d) Thermal insulation in industrial buildings
Roofs and walls - new
Roofs and walls - existing
Economics, grants and subsidies and case studies.

13 **Chartered Institution of Building Services Engineers.** Window design. *CIBSE Applications Manual* AM2. London, CIBSE. 1987.

14 **National Federation of Roofing Contractors Ltd.** Profiled sheet metal roofing and cladding: a guide to good practice. 2nd Edition. London, NFRC, 1991.

15 **Property Services Agency.** Technical guidance, wall and roof cladding: profiled steel and aluminium. PSA Method of Building guide MOB-01 708. London, PSA, 1986.

9.3 Guidance publications - Energy Efficiency Office

Available *free* from **Building Research Energy Conservation Support Unit (BRECSU),** Building Research Establishment, Garston, Watford, WD2 7JR; tel 0923 664258; fax 0923 664097.

16	Low energy factory development.	EPP 173.
17	Low energy factory development.	Final Report No. ED/256/173.
18	Insulated loading doors.	EPP 334.
19	Energy efficiency in industrial buildings.	IL9.

9.4 Further information and bibliography

20 **British Steel Strip Products**. Profiled sheet steel roofs and internal humidity. 1989.

21 **Falconer P.** Metal industrial roofs moisture problems. *The Architects, Journal*, **183**(19) 53-55. 1986.

22 **Falconer P.** Element design guide: roofs: 4 profiled sheet roofs. *The Architects' Journal*, **185** (13) 49-56. 1987.

23 **Jones P and Poole D.** Low energy factories: 1-6. *The Architect's Journal*, **191** May/June. 1990.

24 **Endean F K.** Weatherproofing problems in modern commercial and industrial buildings. *Chartered Institute of Building Technical Information Service* No. 104, 1989.

25 **Jones P J and O'Sullivan P E.** Energy efficient design of industrial buildings. *Building and Environment* **22**, (3) 181-187, 1987.

26 **The European Panel Information Centre,** 74 Albert Mansion, Luxborough Street, London W1M 3LN; tel 071 224 0814; fax 071 935 9464.

27 **Building Research Establishment.** Standard U-values. *BRE Digest* 108. Garston, BRE, 1975.

PART B

SELECTION OF ENVIRONMENTAL SERVICES FOR ADVANCE FACTORY UNITS

PART B - SELECTION OF ENVIRONMENTAL SERVICES FOR ADVANCE FACTORY UNITS

Contents

Contents (continued)

Contents (continued)

1 Introduction

1.1 Scope and aims of Part B

Part B of the Guide concerns the design and installation of services in the Office Area and Production Area. In addition, any fabric fit-out or alterations associated with the reduction of heating load are discussed.

The target audiences for **specific advice** are:

- Mechanical and electrical consultants, either employed by the developer (before the end use is known) or employed by the occupier
- Mechanical and electrical contractors.

The target audiences for **general advice** are:

- Architects
- Developers
- Occupiers conversant with building services, who require more information than is given in the *Occupiers Manual*.

The following information is presented:

- Statutory regulations applicable to environmental systems
- Design data for thermal comfort, lighting levels, and ventilation requirements for all the types of activity likely to occur in an Advance Factory Unit (AFU)
- Checklist of questions designed to ensure that the correct design criteria are considered
- Method for selection for heating, lighting and ventilation systems, outlining the options available for a range of end uses
- Description of each heating, lighting and ventilation system likely to be used in an AFU, outlining principal characteristics, advantages and disadvantages
- Guidance in performance monitoring techniques
- Useful reference documents and publications for further information.

1.2 Cohesive design: the building as a system

The involvement of a building services consultant or contractor at an early stage of the project development can have a significant beneficial effect on the energy efficiency of the completed building.

It is at the early stage of development that the potential energy efficiency of the building fabric is determined. Proper consideration at this stage has a large effect on the attainment of energy efficiency; conversely, the incorporation of poor features in the design will have a detrimental effect, which cannot be compensated for later on.

Hence, the design team, especially the building services representative, has an important role to play during the initial development to ensure that the potential energy efficiency of the building is not compromised by poor design.

Whilst some measures, such as increased insulation levels, involve a small additional capital outlay, it is stressed that many measures do not incur extra cost, being solely the product of thoughtful design and careful construction.

A limited set of options among factory activity, fabric and environmental systems can be created and evaluated to find the optimum application for each end use. This *cohesive design* approach is described in Sections iii-v of the initial Introduction to this Guide, and is represented below.

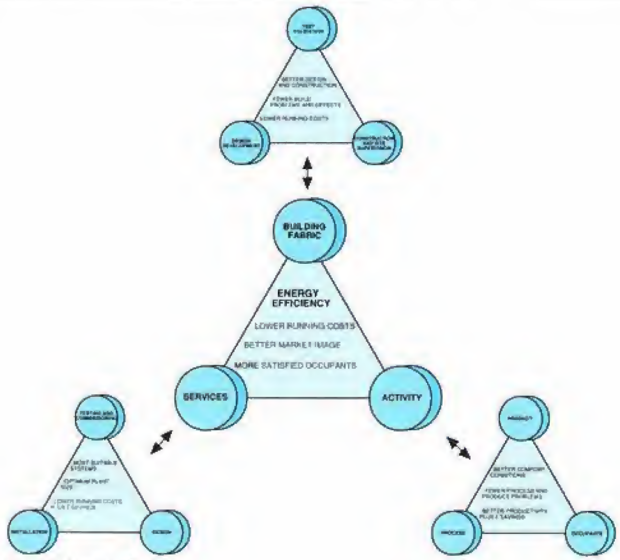


Figure 1(a) Cohesive design

The implementation of the *cohesive design* approach will result in systems which use energy more efficiently to provide better quality accommodation for the activity undertaken in the building.

Heating systems need to be selected with reference to the activity, and sized to match the heat loss of the building. Previous work[36,43,44] has shown that this is particularly important for installations in modern low energy factories, where reduced fabric losses exacerbate overheating problems from systems sized with traditional plant margins. The ability of systems to turn down, from 'heat-up' load to steady state conditions, is becoming increasingly important: a gentler, more even input of heat is needed if large cyclic temperature fluctuations are to be avoided.

Means of ventilation need to be reviewed. As design and construction emphasis on better sealed buildings increases, minimum ventilation requirements may no longer be catered for by uncontrolled air infiltration[7,42].

Considering lighting systems, the correct specification of the type of fitting, coverage and control for any particular purpose is important in ensuring that the correct conditions are created, and that energy costs are minimised.

2 Design information

2.1 Statutory regulations and advisory documents

Many regulations cover the design, installation and operation of environmental systems in a factory. The principal ones are listed below:

Factories Act 1961

Energy Act 1976 and Statutory Instrument 1980/1013 (Amending SI 1974/2160)

Control of Substances Hazardous to Health (COSHH) Regulations 1989

The Building Regulations 1985, in England and Wales; The Building Standards (Scotland) Regulations 1990, in Scotland; or The Building Regulations (Northern Ireland) 1990, in Northern Ireland

British Standards (various)

Health & Safety at Work etc Act 1974.

In addition to mandatory requirements contained in the above regulations, the following advisory documents also apply:

Chartered Institution of Building Services Engineers (CIBSE) Guide 1986

CIBSE Code for Interior Lighting 1984

CIBSE Lighting Guide: The industrial environment 1989

The Institution of Electrical Engineers Wiring Regulations. Regulations for electrical installations. Sixteenth edition 1991

Energy Efficiency Office (EEO) publications (various)

Building Services Research and Information Association (BSRIA) publications (various)

Health and Safety Executive (HSE) Guidance Note EH40/91: Occupational exposure limits 1991

HSE Guidance Note EH22 : Ventilation of the workplace, revised May 1988.

2.2 Design criteria

The data presented in this Section will enable the fundamental environmental requirements to be established.

2.2.1 Indoor temperature

A person's feeling of warmth is influenced by several factors, but 'dry resultant temperature[2]' has been taken as a relatively simple and satisfactory indicator.

Table 2.1 below is derived partly from *CIBSE Guide*[12] (Table A1.3). A range of values for dry resultant temperature is given, these being based on practical experience, and represent conditions in which the majority of occupants are comfortable. Note that female staff generally need slightly higher temperatures to feel comfortable. This should be taken into consideration if the staff is predominantly female.

Table 2.1 Recommended design values for dry resultant temperature

Type of activity	Dry resultant temperature (°C)
Factory Production Area - occupied	
• Sedentary work (generally seated, bench work)	19 - 21
• Light work (light bench work, walking)	16 - 19
• Heavy work (heavy bench work, strenuous activity)	13 - 19
• Stores	15 - 19
Factory Production Area - unoccupied (night set-back)	
• Minimum for frost protection	5
• Minimum for condensation protection	10
Office Area	
• General (seated at desk)	20 - 22

2.2.2 Ventilation - occupants

The minimum requirements are given below for the introduction of fresh air into the working space for ventilation of occupants. The actual ventilation rates may be dictated by other criteria, such as fumes from processes or products. Statutory minima for workspace ventilation are contained in the *Factories Act 1961*[1] and the *Health and Safety at Work etc Act 1974*[6]. The *CIBSE Guide*[12] (Sections A1, A4, B2 and B3) give practical guidance and in addition, the Health and Safety Executive (HSE) has published a Guidance Note EH 22 *Ventilation in the Workspace*[7] which summarises ventilation requirements and ventilation methods.

Table 2.2 Ventilation requirements for occupants
(Extract from *CIBSE Guide*[12] Table A 1.5)

Type of space	Outside air supply (l/s)		Minimum per m² floor area (l/s)
	Recommended per person	Minimum per person	
Factories *	8	5	0.8
Open plan offices	8	5	1.3
Private offices, cafeteria	12	8	1.3
Kitchens (small)			20 extract
Toilets *			10 extract

* In addition to statutory regulations, local bylaws may apply.

In general terms, the following points should be noted:

- **Office Area**: For the majority of Office Areas, natural ventilation will provide adequate ventilation.

- **Mechanical ventilation** may be needed for dense occupancy, or where the opening of windows is not desirable, because of excessive noise or air borne pollution.

- **Kitchens and toilets**, if located adjacent to an external wall, can be naturally ventilated using opening windows.

- **Production Area**: Sufficient ventilation for Production Areas may be provided by incidental air leakage. However, recent work[42] indicates that with improvements in building standards aiming to reduce infiltration rates for energy efficiency purposes, air infiltration through the fabric may no longer be relied upon to provide the recommended minimum ventilation rates derived from floor area. Permanent, controllable, means of ventilation, relating to the number of occupants or building floor area, should be considered.

- **Summer ventilation**: It is normal practice to provide extraction for summer ventilation via fans mounted in the roof or in the walls, to limit overheating resulting from occupants or heat producing equipment. The extraction rate generally used is equivalent to 2 - 4 air changes per hour (ac/h), based on the volume of the production space. Fan speed control should be provided, to allow the extraction rate to be matched to ventilation requirements, ie 2 ac/h may be sufficient under normal conditions, but 4 ac/h may be needed during the height of summer or with a large occupancy.

2.2.3 Ventilation - production activity

- **Warehousing and light bench work**: Activities in the Production Area not involving the emission of airborne contaminants do not impose additional ventilation requirements; the minimum fresh air supply rates will be dictated by the number of people or the floor area.

- **Industrial processes** which emit fume, dust or other contaminants into the workspace impose further ventilation requirements. Statutory regulations such as the *COSHH Regulations*[3] lay down minimum requirements to be met. In addition, *HSE Guidance Note EH40/91*[8] gives occupational exposure limits for various substances. The range of industrial ventilation solutions is as large as the range of contaminants it is designed to control, but the general aims can be summarised as follows:

  Ventilation requirements will depend upon the type of contaminant (ie gaseous, particulate or fume), toxicity, rate of emission, number and spread of emission sources

  For airborne contaminants of low toxicity or small rate of emission, satisfactory conditions can be achieved by dilution or displacement ventilation

  In most cases, the best means of control is containment of the emission by local extraction, exhausting outside.

On all but the smallest extract systems, replacement or make-up air should be provided to balance the exhaust air. This make-up air may need to be tempered before supply into the working space, to avoid occupant discomfort.

2.2.4 *Lighting*

A large number of statutory regulations are in existence relating to the lighting requirements in various types of premises. However, much of the relevant legislation for a particular area will be contained in more general legislation such as: *Health and Safety at Work etc Act, 1974; Offices, Shops and Railway Premises Act, 1963; Factories Act, 1961; Protection of Eyes Regulations, 1974 amended 1975.*

A typical provision is that of the *Offices, Shops and Railway Premises Act,1963 Section 8 (1)*; "Effective provision shall be made for securing and maintaining, in every part of the premises to which this Act applies in which persons are working or passing, sufficient and suitable lighting whether natural or artificial".

In addition to these regulations there are various recommendations and codes of practice that specify lighting levels in detail. Also, guidance is available on good practice in the design and use of lighting installations[21,29,39,40].

The lighting level recommendations generally accepted within the lighting industry are those contained in the *Chartered Institution of Building Services Engineers (CIBSE) Code for Interior Lighting 1984*[13] and the *CIBSE Lighting Guide: The industrial environment, 1989*[14], which represent good lighting practice. These recommendations are generally more onerous than the requirements of statutory legislations, which are normally concerned with what is adequate.

Table 2.3 gives the recommended levels of illuminance for a range of activities and interiors.

Table 2.3 Examples of activities/interiors appropriate for each standard service illuminance
(Extracts from *CIBSE Guide*[12] Table A1.6)

Standard service illuminance (lux)	Characteristics of the activity/ interior	Representative activities/ interiors
100	Interiors visited occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail	Corridors
150	Interiors visited occasionally with visual tasks requiring some perception of detail or involving some risk to people, plant or product	Loading bays, stores, switchrooms
200	Continuously occupied interiors, visual tasks not requiring any perception or detail	Monitoring automatic processes in manufacture
300	Continuously occupied interiors, visual tasks moderately easy, ie large details greater than 10 min. arc and/or high contract	Packing goods, rough sawing
500	Visual tasks moderately difficult, ie details to be seen are of moderate size (5-10 min. arc) and may be of low contrast. Also colour judgement may be required	General offices, engine assembly painting and spraying
750	Visual tasks difficult, ie details to be seen are small (3-5 min. arc) and of low contrast, also good colour judgement may be required	Drawing offices, ceramic decoration
1000	Visual tasks very difficult, ie details to be seen are very small (2-5 min. arc) and can be of very low contrast, also accurate colour judgement may be required	Electronic component assembly gauge and tool rooms, retouching paintwork
1500	Visual tasks extremely difficult, ie details to be seen extremely small (1-2 min. arc) and of low contrast. Visual aids may be an advantage	Inspection of graphic reproduction, hand tailoring fine die sinking
2000	Visual tasks exceptionally difficult, ie details to be seen (less than 1 min. arc) exceptionally small with very low contrast. Visual aids will be an advantage	Assembly of minute mechanisms, inspection of finished fabrics

3 Check lists for preparation of brief

3.1 Building fabric - general check list

There are two principal areas affecting energy use of a building which are defined at the planning stage. The building services engineer should endeavour to see that these are properly considered by the design team.

3.1.1 Air infiltration

Although construction standards have a large effect on the leakiness of the fabric, there are several factors which should be considered to reduce air infiltration:

1 Avoid installing goods doors facing the prevailing wind

2 Use of windbreaks on exposed sites

3 Detailing of junctions between fabric elements (particularly important in sheet construction).

3.1.2 Thermal transmittance performance; daylighting and natural ventilation

4 Consider increasing insulation levels

5 Optimise glazing area to balance the increased heat loss with increased daylighting. This applies to rooflights in the Production Area and to Office Area windows. Note that increased daylighting is of benefit to energy efficiency only if artificial lighting levels are modulated (eg by perimeter switching) in conditions of sufficient daylight.

6 Care should be taken in sizing office window areas to avoid summer overheating. Ensure the opening area of the glazing for office windows is maximised, to make best use of natural ventilation.

3.2 Services - Office Area check list

These are usually installed as part of the developer's fit-out, and the primary criterion is, usually, low cost.

However, not all energy efficiency measures incur extra cost, but instead can result primarily from good design. Hence the building services consultant or contractor should consider all the following check list points within the financial constraints.

Check list for preparation of brief: Office Area

3.2.1 Heating and domestic hot water

1 Consider use of condensing boilers in wet systems.

2 Separate domestic hot water heating from space heating by using:

- Electric point-of-use heaters
- Gas-fired water heaters for larger loads
- Combination boilers.

3 Provide sufficient controls for heating system:

- Optimised start
- Compensated control for wet systems
- Thermostatic control.

4 Consider future sub-division of area and incorporate facility for zone heating system, including controls, to match.

5 Avoid the use of air conditioning: if it is required (eg for computer areas), minimise treated volume and avoid specification of narrow ranges of temperature and humidity. Use controls with adjustable dead zone or proportional band to maximise the energy cost benefit from the widest tolerable range of temperature and humidity.

3.2.2 Lighting

6 Provide efficient fluorescent fittings in all areas; avoid the use of tungsten GLS lamps - use compact fluorescent fittings.

7 Provide adaptable and flexible switching arrangements to allow:

- Changes to office layout (individual office switching etc)
- Perimeter switching
- Reduced lighting levels for cleaners, security staff.

8 Consider photoelectric control for perimeter fittings.

3.3 Services - Production Area check list

It is important that the contractor or consultant recognises the precise requirements of the occupier. The aim of this Section is to ensure that the use of the building is fully described, in order to set out the correct criteria for design and selection of environmental systems, suitable for the activity undertaken in the building.

The questions below are designed to act as a prompt, and are intended to stimulate discussion of the design criteria. The list should not be considered comprehensive.

This list has been compiled with reference to the more general *BSRIA Design Briefing Manual*[9]. Further assistance can be obtained from the *British Standard Code of practice for: energy efficiency in buildings*[11] and elsewhere[19].

Note: Both present and future requirements should be accounted for, in giving details on the following.

Considering Figure 1 (see also Section 4.1), the information required for the brief can be categorised into:

- **Building fabric**
- **Services**: heating, domestic hot water, ventilation, lighting and electrical
- **Activity**: occupants, process and product.

Check list for preparation of brief: Production Area

3.3.1 Building fabric

Information for brief	Energy efficient solutions/ design criteria
1 Do the goods doors face the prevailing wind?	Consider external wind breaks. Use draught reduction in goods loading area (partition off, rapid closing doors, plastic strip curtains).
2 Is the site exposed?	As above.
3 Is the Production Area to be partitioned into smaller areas?	Care needed in selecting heating systems. Lighting should be zoned to match areas. Install flexible lighting layout and switching arrangements to allow changes of area layout.
4 Are mezzanine floors to be installed?	As 3.
5 Is the full height to eaves needed in all areas?	Install false ceilings to reduce space heating volume. ***Note 1*:** Ventilation needs to be carefully considered if volume is reduced. ***Note 2*:** Ensure any holes or gaps in the false ceiling are sealed to prevent leakage of warm air into ceiling void.
6 Are the offices to be partitioned?	Check for adverse effects on uniformity of heating and ventilation.

3.3.2 Services: General

Information for brief	Energy efficient solutions/ design criteria
7. Check supply capacities for water, gas and electricity are sufficient for the process and building.	
8. For each activity establish (using the design data tables) the specified values for:	
• minimum temperature	See Table 2.1.
• minimum fresh air requirement (based on occupancy)	See Table 2.2.
• lighting level.	See Table 2.3.

Information for brief	Energy efficient solutions/ design criteria
Equipment such as computers and process machinery may impose further limits for: • maximum temperature • maximum and minimum humidity • maximum dust levels.	Avoid unnecessary restriction on environmental conditions, which could impose stringent requirements on air conditioning system design.
9 Is the selection of low maintenance equipment required? (This may incur additional capital cost.)	Ensure that systems specified can be understood by those who operate and maintain these.
10 Is equipment accessible for maintenance without causing major disruption to production?	
11. Would standardisation of main components (light fittings, heating equipment) be preferable?	

3.3.3 *Services: Heating*

Information for brief	Energy efficient solutions/ design criteria
12. Are any future reorganisations of the Production Area forseen?	Subdivide heating system to facilitate zone control, present or future.
13. Are there large areas with low occupancy, in which heating is not required other than for occupants or care of building or its contents?	Provide spot heating over occupied areas:
14 Is the roof high in the Production Area (over 6-7m)?	Choose heating systems that minimise stratification, and take advantage of any fortuitous heat gains, eg from occupants, machines, lighting, solar gains.
15 How important is the uniformity of heat distribution? State maximum temperature range acceptable.	

Information for brief	Energy efficient solutions/ design criteria
16 Is condensation protection required?	Two alternatives: maintenance of: • minimum temperature • maximum humidity level. Dehumidification can be an energy efficient option where heating is not specifically required for products or people.
17 Do any processes or products require close environmental control? State limits if known.	Enclose areas of special environmental control to minimise treated volume. Locate control sensors in representative places, ie not in sunlight, draughts, above radiators. Provide, where possible, a radiant heating component to improve comfort (Refer to Section 5.2 for explanation).

3.3.4 Services: Ventilation

Information for brief	Energy efficient solutions/ design criteria
18 Is low air movement or are low dust concentrations required, eg for electronic component manufacture?	State level of cleanliness required if known.
19 List products or processes imposing ventilation requirements, and state type, source and amounts of the following: • solvents • fumes • dust • moisture vapour.	State any known ventilation requirements (eg from manufacturers' data). Consider requirements imposed by *COSHH Regulations*[3]. Use natural ventilation where possible. Use cool night air to flush building in summer.

3.3.5 Services: Lighting and electrical

Information for brief	Energy efficient solutions/ design criteria
20 List electrical equipment voltages and kW loads of permanent plant items.	Consider benefits of fortuitous gains and heat recovery.
21 Is spark proof, dust proof or splash proof electrical equipment required (for use with inflammable or explosive products or processes)?	
22 What lighting levels are required by the process?	Use highest efficiency discharge lamps where acceptable. Use flexible lighting layout permitting relocation of fittings as required. Use decorative, display and security lighting only where necessary. Take advantage of light coloured finishes. Consider reduced overall lighting with matched task lighting.
23 What lighting controls are required?	Provide switching arrangements with sufficient circuits to segregate intermittently used fittings such as fittings near windows or intermittently occupied areas. Locate manual switches in the area illuminated. Provide special switching for use by cleaners (lower lighting levels allowable). Include legends on switches, especially the multi-gang type subdividing large areas. Consider automatic photoelectric control. Consider timers to turn off lights in areas used intermittently.

3.3.6 Activity: General

Information for brief	Energy efficient solutions/ design criteria
24 State nature of activity.	

3.3.7 *Activity: Occupants*

Information for brief	Energy efficient solutions/ design criteria
25 State primary Production Area activity level of occupants.	See Table 2.1.
26 State other activities (foreman's office, storage area).	Zone heating system for different user requirements.
27 State number of occupants to enable fresh air requirements to be calculated	See Table 2.2.

3.3.8 *Activity: Process*

Information for brief	Energy efficient solutions/ design criteria
28 State process (if any).	
29 List gas burning equipment in kW loads, process machinery and equipment.	Consider utilisation of recovered heat from waste heat sources.
30 State patterns of usage of equipment.	
31 List noise ratings of process plant items.	Noise attenuation may be required: obtain specialist advice.

3.3.9 *Activity: Product*

Information for brief	Energy efficient solutions/ design criteria
32 State product of process or activity.	Consider heat recovery from waste heat sources.

4 Achieving energy efficiency

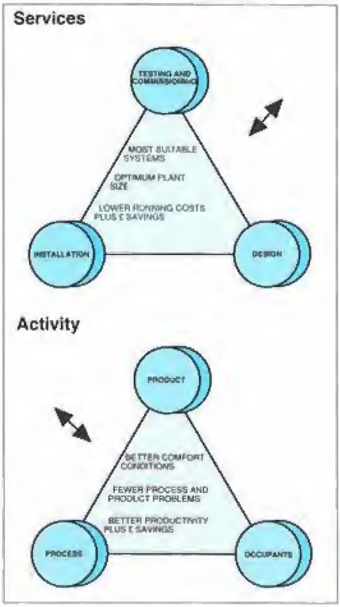
The reasons for the choice of a particular building by the occupier are likely to be its location, size and rental charges.

Once a building has been selected and taken over, the priority is to set up the production facility as quickly as possible. Despite the commercial pressures on time, it is important at this stage to consider that the fitting out of this area, and the systems installed, will have a very large effect on the future running costs of the building. Any running cost savings will potentially continue over the lifespan of the installation.

4.1 Matching services to building fabric and activity

It is important to match the services with the building characteristics and the activity.

This principle of *cohesive design* is illustrated by Figure 1, page B6. All three elements, building fabric, services and activity are inter-related, and choices made on any one affect the others. The energy efficiency of the occupier's operation is likely to be affected by these interactions.



In the development of AFUs, the end use is, by definition, unknown. However, it is possible to predict the *likely* end uses, and hence the aim is to develop buildings flexible enough to accommodate a range of activities.

Starting from the **building fabric** as a bare shell, an integrated scheme can be developed which matches the requirements of the activities to suitable environmental systems, which in turn are matched to the building fabric. The building fabric can be modified as part of this process to reduce heating loads (by air leakage control).

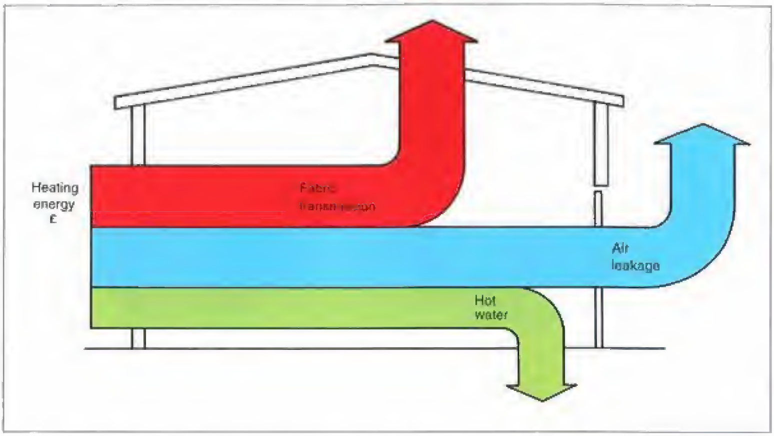
Once the most suitable type of **services** have been selected, efficient systems can be obtained by correct design and careful installation, and satisfactory performance confirmed by testing and commissioning.

The criteria imposed by the **activity** are the environmental requirements of the process, product and occupants

4.2 Energy use and costs

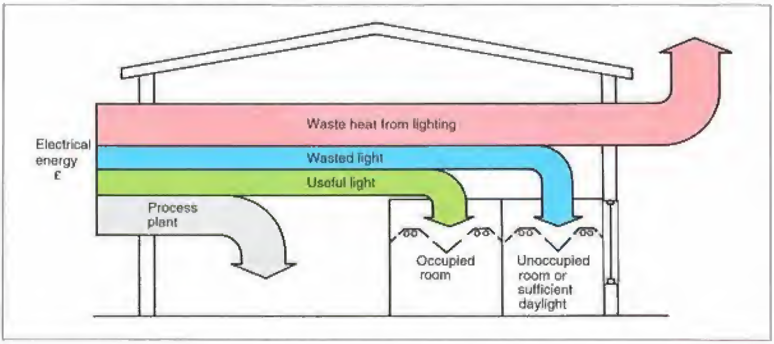
Heating is usually provided by the combustion of gas or oil or the consumption of electricity. Other energy sources, such as coal, wood, solar, although possible are considered inappropriate for general consideration.

The distribution of the energy used for heating is represented by the diagram below:



The rate of heat loss through the fabric is dictated by the U-value and is effectively decided at design stage. The two other components, accounting for the majority of the heat loss, are air infiltration/leakage and domestic hot water. Minimising these will reduce heating energy consumption.

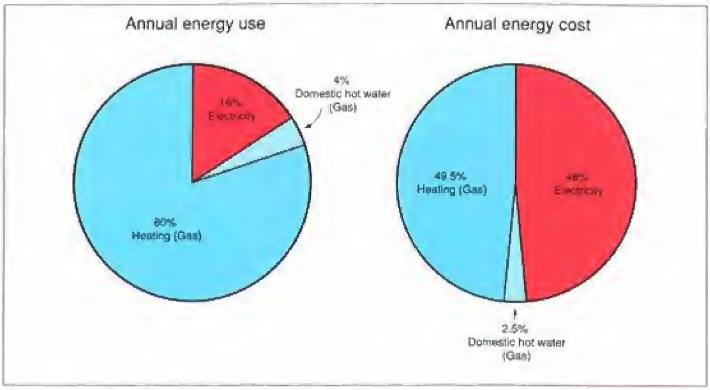
Electricity is used for running plant or processes (not considered in this Guide), and for lighting. A typical breakdown is indicated below:



All lighting energy ends up as heat. High efficacy lamps use less energy to provide the same amount of light.

The diagram below illustrates the energy use breakdown of a typical AFU with gas heating. It is important to note that whilst electrical energy use is of the order of 16% of total energy use, the *cost* of electrical energy is much higher, approaching half the total energy bill.

Therefore, equal priority should be given to reducing electricity consumption as is given to reducing gas consumption.



4.3 Air infiltration control

4.3.1 Sources of heat loss

The principal sources of heat loss in a building are:

- **Transmission loss through the building fabric by conduction:** This is controlled by the application of, at least, the minimum standards of insulation dictated by the Building Regulations.

- **Infiltration loss resulting from building 'air leakage':** Warmed air escapes to the outside, driven by buoyancy effects or wind pressure or by unbalanced mechanical ventilation, via small gaps in the building, usually roof ridges, eaves, and around the frames of the windows and doors. This is generally dependent upon the built standard.

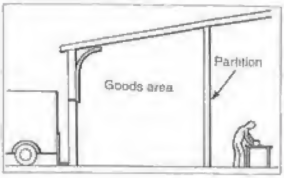
- **Infiltration loss resulting from building use:** This is under the direct control of the occupants, and will depend entirely on the way the building is used and the features, if any, incorporated to control this loss, particularly for goods doors. It is important to note that this source of infiltration loss can far outweigh the other heat losses, and can contribute significantly to the running cost of the building.

4.3.2 Goods door infiltration loss

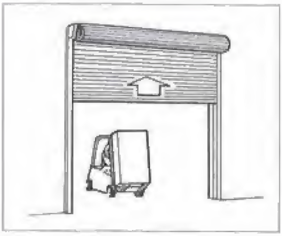
The largest source of air leakage is usually the goods door and hence this is the most significant source of heat loss. The configuration of goods doors at opposite ends of the building should be avoided, but if inevitable, then special draught reduction measures are essential. Improving ease of use (push button or automatic operation) can help to ensure that doors are closed whenever possible. Occupier awareness of the costs savings available by closing doors is also important.

This loss can be controlled by installing draught reduction measures at the loading bay doors; the principal types are described below.

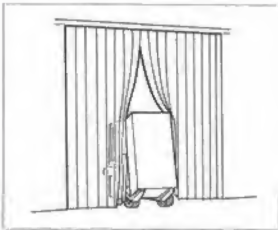
- **Partitioning** off the loading bay area, either internally or externally. This can substantially reduce air leakage heat loss, but unless the partitioning is insulated to the same level as the wall, the fabric transmission loss will increase if the loading bay door is left open, as the partitioning effectively becomes an outside wall. In addition, the partition needs to be well sealed to prevent air leakage.



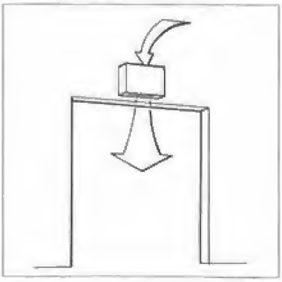
- **Rapid closing doors**, useful for frequent use.



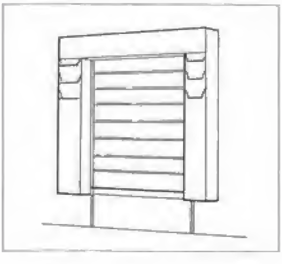
- **Plastic strip curtains** can reduce draughts and hence air leakage heat loss, but if the outer door is left open for long periods, substantial heat loss will occur. These draught curtains are not a substitute for closing the doors.
  Note: Safety implications must be considered carefully, as visibility through the curtain is reduced significantly.



- **Air curtains** mounted over the loading bay doors. These can improve comfort levels inside, at the expense of high running costs.



- **Pneumatic seals** to vehicle loading bay.



4.4 Heating plant size

Once the heat loss has been quantified more closely by installing air leakage control measures, the size of the heating plant can be assessed more accurately.

This has several advantages:

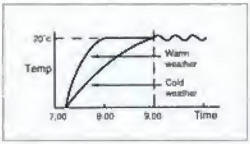
- Reduced plant size, reduced capital cost
- Plant operating at or near full load is generally more efficient
- Reduced chance of overheating of work space.

4.5 Heating system control

The type of control of the heating system used can have a large effect on the ability to produce comfortable conditions for the occupants, and on the running costs of the plant. This is especially so in low energy factories, where the heating power requirement to reach the desired temperature is substantially higher than that needed to maintain the temperature.

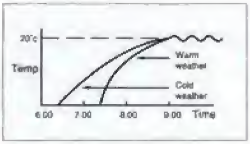
There are two different types of plant start control:

Fixed time start



This control starts the heating plant at a fixed time (set by time-clock). In spring or autumn the set temperature will be reached more quickly, and hence the area will be unnecessarily heated for a period before occupancy, unless the time-clock is adjusted regularly to take account of differing weather conditons. It is the simplest and cheapest type of start control.

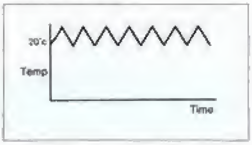
Optimum start



This type of control can make an allowance for the heat-up rate of a particular building, and the changes in outside temperature. It can save energy by only switching on the heating just in time to achieve the working temperature before occupancy. A number of refinements can be incorporated in optimiser control units: the start-up can involve elevated system flow temperature, low internal space temperature limits, frost protection and provision for different programmes after weekends or long off-periods. Early-off optimiser functions and adaptive self learning characteristics are also available.

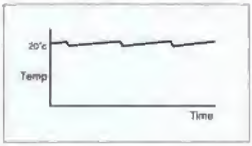
The main types of set temperature control are:

On/off control



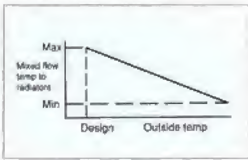
This type of control has the lowest installed cost, and can provide acceptable conditions with careful design, but the disadvantage is the large cyclic variations in temperature owing to plant switching on and off.

Modulating control



This modulates the heat output to match more closely the requirements during occupancy, avoiding excessive temperatures and cycling, thus providing improved conditions whilst using less energy than on/off control.

Compensated control



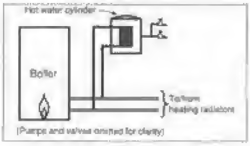
Used with hot water 'central heating' systems, this compensates for milder outside temperatures by reducing the hot water temperature supplied to the radiators.

Installed controls *must* be used to best advantage: ensure that thermostats are set and operate correctly and time-clocks match occupancy requirements.

4.6 Domestic hot water

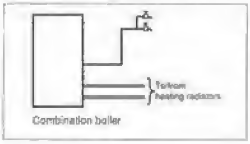
The domestic hot water services are generally provided as part of the developer's fit-out of the Office Area, and can be one of the following options:

Central storage tank



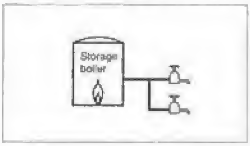
The storage cylinder tank is heated indirectly by the main central heating boiler. Usually the cheapest system to install, if a central heating system is being installed, but means that a large boiler runs during the summer to provide for a small domestic hot water (DHW) load. Not energy efficient unless DHW load is large. An electric immersion heater for summer use would reduce costs.

Combination gas fired boiler



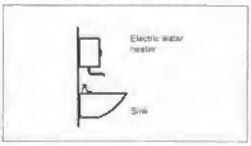
Hot water is supplied only on demand, independently of heating requirements. An energy efficient option for small to medium sized applications, as there is no storage loss.

Separate central gas-fired water storage heater



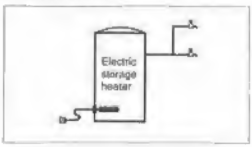
Hot water is supplied only on demand, independently of heating requirements. An energy efficient option for small to medium sized applications, as there is no storage loss.

Electric point-of-use water heaters



Usually installed over sinks (but undersink units available). These provide the most energy efficient solution for small DHW loads (most factories fall into this category).

Electric storage heater



Water is heated using low tariff off-peak electricity, to be drawn off during the occupancy period.
High insulation levels of the storage vessels ensure standing losses are minimised, and hence this can be an energy efficient option for small to medium sized applications, with short draw-off legs.

If the first option above has been installed, then consideration should be given to the viability of installing one of the other systems. Performance monitoring techniques can be employed to assess the cost of energy used to generate hot water supplies from central boiler plant. This can be compared with the cost derived from the amount of hot water actually consumed. The difference may justify changing the hot water system to one of the more energy efficient choices.

Consideration should also be given to installing spray taps, as these can substantially reduce hot water consumption.

4.7 Ventilation

Ventilation requirements for various industrial activities are described in Section 7.4. The means by which the energy efficiency of the ventilation system can be optimised are described below.

4.7.1 Natural ventilation

This may be infiltration through the fabric of the building, or planned, natural ventilation through fixed openings, or by opening vents or windows. Infiltration rates will vary according to external wind strength and internal temperature differential, and, as such, are not controllable. The better solution would be to ensure that the fabric infiltration rate is minimised, and incorporate adjustable openings to provide natural ventilation. These openings can then be adjusted to take account of external wind pressure and internal temperature differential, to provide the appropriate level of ventilation to suit the activity taking place.

4.7.2 Extract ventilation

Effectiveness of extract ventilation can be maximised by ensuring that the extraction point is as close as possible to the source of emission, thereby achieving efficient containment and minimising the volume of heated exhaust air. If the extraction volume is limited, then no special provisions need to be made for air replacement or fresh air make-up. For larger volumes, fresh air make-up can be provided via fixed vents close to the point of extraction. In these cases, care needs to be taken in the design of fresh air inlets to avoid draughts which may disrupt air flow patterns and hence reduce fume capture efficiency.

All types of heating systems could be used in conjunction with this type of ventilation.

4.7.3 Balanced ventilation

If the volume extracted is large, the make-up air will require heating to match the internal temperature before supply to the heated space. There is a cost penalty in warming up supply air and exhausting contaminated air to atmosphere and, at some point, there will be an economic case for installing some type of heat recovery equipment, in which waste heat from exhaust air is used to pre-heat incoming air.

Warm air heating systems are most suitable if this kind of ventilation is required.

4.8 Lighting

The energy used for lighting is a product of the power consumption of the fitting and the length of time illuminated.

Therefore, energy can be saved by:

- Using light fittings which provide the highest light output for a given power input (high efficacy). For given types of lighting, eg, fluorescent, high pressure mercury etc., particular units can be selected which have high efficacy.

- Matching the lighting levels to each activity. Consider reducing light levels during lunchtimes or for cleaners, by switching off some of the fittings.

- Only illuminating the lamps when required. Control of lighting is important in attaining energy efficiency. Unless switching arrangements are convenient to use, lighting tends to be left on all day. Provide clearly labelled switching, incorporating zoning to allow light fittings to be switched off in good daylight conditions, eg perimeter fittings adjacent to windows; fittings in areas daylit by rooflights.

- Informing the occupier in the correct use of lighting.

5 Environmental systems

5.1 General

The following Sections give an outline of the basic principles of environmental services; a selection procedure for services for the Office Area and the Production Area; descriptions of each of the environmental systems.

This selection process can be used in:

- Preparing a brief for the services fit-out of a new building
- Preliminary selection of systems for budgeting purposes
- Preparation of designs for environmental systems.

The gains to be made from the proper selection and careful installation of energy efficient systems can be totally negated by inefficient use. Therefore, it is of great importance that the building services designer gives advice to the occupier on energy efficient practices, stressing the financial benefits and the favourable effect on the workforce of correct environmental conditions.

The principal good housekeeping practices are:

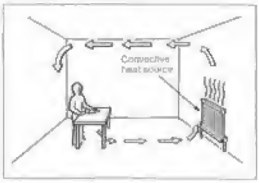
- Correct setting of temperature controls
- Correct setting of heating time-clocks
- Closing of external doors after use, especially goods doors
- Switching off lighting when not required.

5.2 Space heating

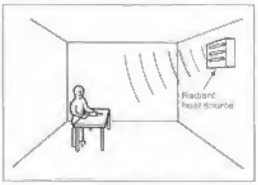
5.2.1 Heating terms

Heat emission comprises two elements:

- **Convection:** The air in or adjacent to the heat source is warmed and circulated by natural or blown air movement. With this type of heating the temperature tends to increase at high level causing stratification. This can be a problem, in particular, in buildings over 5m high. Use of destratification fans to assist air circulation should be considered.

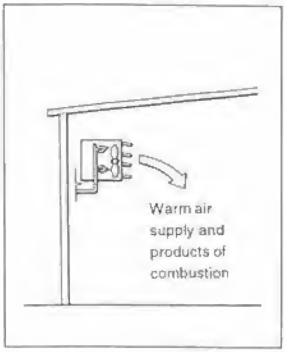


- **Radiation:** The heat source emits heat radiation in a similar manner to the sun. People and objects absorb the radiation and warm up. The warmed floor and furniture raise the temperature of the surrounding air by convection. This has particular advantages in high bay situations where heat is required only at low level.



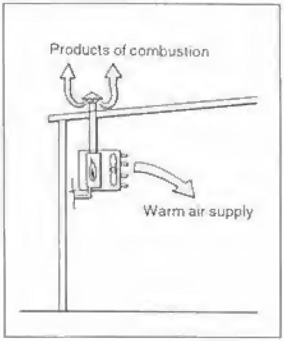
Fuel can be burnt to provide heat in two ways:

- **Unflued heating:** Applicable to oil- or gas-fired systems, where the fuel is burnt directly in the air supplied to the space, ie the 'fumes' are blown into the heated area, along with the heated air. This is only suitable in situations where there is a high ventilation rate to dilute the air to prevent the build-up of fumes and moisture.



- **Flued heating:** The fuel is burnt in a heat exchanger which transmits the heat to the air blown into the space. The fumes from the burning of the fuel are flued to outside. Most systems installed in AFUs are of this type.

Note: Warm air heaters have been used to illustrate this principle, but it applies equally to U-tube radiant heaters, which also may be flued or unflued.



5.2.2 *Heating fuels*

- **Gas:** Natural gas or liquified petroleum gas (lpg) - butane, propane - is the most commonly used fuel for space heating. Gas heating systems fall into two categories:

  Gas burnt directly in the heater unit providing either radiant or convective heat; these systems can be either flued or unflued

  Gas burnt in a boiler to heat water/steam which is then circulated to heat emitters, providing radiant or convective heat.

- **Oil:** This can be used instead of gas for direct firing in warm air heaters, or for firing boiler plant supplying a hot water or steam heating system. Dual fuel boilers are available, which can be converted to run on either fuel.

- **Electricity:** Electric heating systems can be categorised by the tariff rating of the electricity used:

  Standard or day tariff heaters include warm air fan convectors and quartz radiant heaters. Because of high running cost, these are only used for heating small areas, or for spot heating (with quartz radiant), or where process requirements dictate strict temperature control and cleanliness.

Night or Economy 7 tariff heaters operate by storing heat during the low tariff period and releasing it on demand during the day. These are a viable alternative to oil or lpg in terms of running cost, and are generally considered when natural gas is not available.

- Other fuels and energy sources can be considered where unusual circumstances make these attractive.

5.2.3 Heating media

Where a central boiler plant is used, the following media can be used to transport the heat to the heated area.

- **Hot water:** This is used in the majority of domestic and office type accommodation and is used to transport heat from a central heating plant to a number of heat emitters ; these are usually radiators in a low temperature hot water system (LTHW), or fan convectors or radiator panels in a medium temperature hot water (MTHW) system. These are not commonly used in AFUs owing to high capital costs, unless the Production Area is converted into office type accommodation with false ceilings, and is used for mainly sedentary work.

- **Steam:** Where steam is generated for process requirements, it can be utilised for space heating, using fan convector units mounted at high level. High cost precludes generating steam solely for space heating.

5.2.4 Fire risks

Extensive assessment of the fire risks associated with each type of heater is outside the scope of this Guide. However, the following general principles should be noted:

- Open element radiant type heaters, whether using gas, oil or electricity, present a greater fire risk than convector type heaters

- Flued appliances are preferable to unflued

- Clear space should be maintained around all types of heater. Guards should be fitted to prevent contact with combustible materials.

5.3 Ventilation

5.3.1 Supply air and tempered supply air

Supply air is delivered to the space to balance air extracted.

An unheated supply can be delivered locally to make up an extracted air volume. This is only suitable for small air volumes, to avoid cooling the space.

Tempered supply air is heated to match the internal space temperature before delivery, to avoid draughts and reduction of space temperature.

5.3.2 Extract air

Air removed from the treated space may be a small local extract for controlling fume, or a large general extract.

5.3.3 *Balanced supply and extract air*

Combination of the above supply and extract to balance air delivered and air removed, to avoid pressurising the space.

5.4 Lighting

5.4.1 *Lighting terms*

- **Lux:** The SI (System International) basic unit of illumination is lux (lumen/m^2).
- **Lumen:** A measurement of the rate of flow of luminous energy.
- **Efficacy:** The measure of efficiency of a light source, being the ratio between light output in lumens and electrical power input in watts.

5.4.2 *General lighting principles*

The principal lighting objectives are to:

- Facilitate quick and accurate work
- Contribute to the safety of those doing the work
- Create a good visual environment.

5.4.3 *Lighting categories*

Lighting systems fall into three categories:

- **Uniform or general lighting:** Lighting systems which provide an approximately uniform illuminance on the horizontal working plane over the entire area are called general or uniform lighting systems. The luminaires are arranged in a regular layout, giving a tidy appearance to the installation. General lighting is simple to plan and install and requires no co-ordination with task locations, which may not be known, or which may change. The greatest advantage of such a system is that it permits flexibility of task location. Its major disadvantage is that energy is wasted illuminating the whole area to the level needed only for the most critical tasks.

- **Localised lighting:** Localised lighting systems employ an arrangement of luminaires related to the position of tasks and work stations. These provide the required service illuminance on work areas, together with a lower level of general illumination for the space. By careful luminaire positioning, good light utilisation is achieved with few problems from shadows, reflections and discomfort glare. Localised systems normally consume less energy than general systems, unless a high proportion of the area is occupied by work stations.

- **Local lighting:** Local lighting provides illumination only over the small area occupied by the task and its immediate surroundings. A general lighting system is installed to provide sufficient ambient illumination for circulation and non-critical tasks; the local lighting simply supplements the general lighting to achieve the necessary illumination on tasks. The system is sometimes referred to as task-ambient lighting. It is a very efficient system, particularly when high standards of task illuminance are required.

Local lighting is commonly provided by luminaires mounted on the work stations, providing a very flexible room layout. Such local units must be positioned carefully to minimise shadows, reflections and glare. These offer some personal control of lighting which is often a popular feature in a large open office.

5.4.4 *Lighting characteristics*

- **Colour rendering:** The extent to which a lamp type will give surface colours the same appearance as these have under a reference light source (usually daylight). Excellent colour rendering implies no distortion of surface colours.

- **Run-up time:** Tungsten, tungsten halogen and tubular fluorescent lamps produce significant amounts of light immediately when switched on. All the other lamps types require several minutes to approach full light output; this may be important where installations have to be used at unexpected times.

- **Restrike time:** Tungsten, tungsten halogen and tubular fluorescent lamps can be switched off and then switched on again immediately. All the other lamp types, unless fitted with special control gear, show a significant delay after switch-off before these will re-ignite. This characteristic may have important safety implications as momentary interruption in the electricity supply can extinguish these lamps and it may be some time before these can be re-lit.

Lamps with long run-up times or restrike times are not suitable for use with automatic control incorporating light level or occupancy sensors which impose frequent switching.

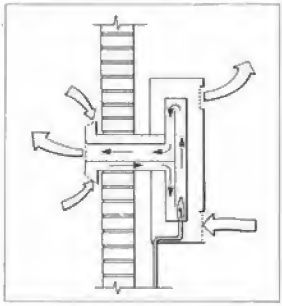
6 Environmental systems selection - Office Area

6.1 Office Area heating

General

The choice of heating for offices is likely to be influenced by the size, location, type of construction and perceived image of the offices.

6.1.1 Gas convector heaters



Description

The units burn natural gas or propane, and are mounted on an external wall with a balanced flue through the wall. The burners modulate to control heat output under thermostatic control.

Energy efficiency

Typically 75%.

Controls

Usually supplied with thermostatic control mounted on unit, but models are available which can be wired to a central room thermostat controlling a number of units.

Maintenance implications

Burners require yearly servicing.

Advantages

- Simple and quick to install: no other plant required
- High overall efficiences (no transport losses)
- Cost effective, particularly for small office applications
- Low running costs.

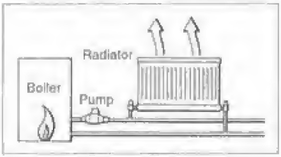
Disadvantages

- Units are bulky compared with LTHW radiator
- Balanced flue outlets on external wall - limits location of unit
- Flue outlets may be visually unacceptable
- High surface temperature.

Applications

- Small to medium sized offices.

6.1.2 *Low temperature hot water radiator systems*



Description

A gas- or oil-fired boiler heats up water which is distributed around a radiator circuit. The boiler may be of conventional or, more efficient, condensing type[16,20]. The boiler and associated plant can be located remote from the heated area. The system can also be employed to supply domestic hot water, although this is not an energy efficient option unless the hot water load is substantial.

Energy efficiency

- Depends on system specification and design.

Controls

- Depends on system specification and design
- A good control concept is essential in achieving energy efficiency
- The minimum requirement for an efficient system is normally the use of thermostatic radiator valves or room thermostats, optimised start and weather compensation.

Maintenance implications

- Boiler requires twice yearly maintenance
- Associated plant and system require periodic inspection.

Advantages

- Centralised control at boiler plant
- Proven technology
- Occupants familiar with system, being similar to domestic installations
- Flexible layouts of plant and emitter location
- Emitters small in size compared with gas convectors and electrical storage heaters

- Low running costs (if properly designed and run)
- Good temperature control possible.

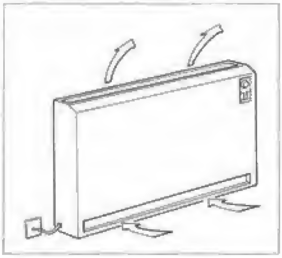
Disadvantages

- Labour intensive installation
- Water used as heating medium; risk of freezing, leaks etc
- Separate plant space required
- Higher capital cost than other systems, especially for small areas.

Applications

- Medium and large office areas.

6.1.3 Electric storage heaters



Description

Heaters store heat during the Economy 7 overnight tariff and discharge the stored heat, on demand, during the day.

Some units are available with built-in panel heater elements, operating off normal tariff electricity to provide 'top-up' heating.

Energy efficiency

Up to 95% of delivered electrical energy input. Losses limited to casing loss during charging period, and depend upon levels of insulation employed.

Controls

- Units usually supplied with thermostatic control mounted on unit
- Automatic controls are available which optimise the heat change stored, in relation to the external temperature.

Maintenance implications

None.

Advantages

- Simple to install
- Low capital cost.

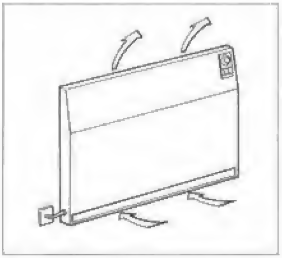
Disadvantages

- High fuel cost leads to generally higher running cost compared with gas systems
- Large size of units.

Applications

- Offices where natural gas supply is not available. Running costs are comparable with manufactured gas systems
- Small, well-insulated offices, in cases where running cost would be insignificant and capital cost of other systems cannot be justified
- Can be installed to provide base heat output, with panel heaters (either built-in or separate) providing top-up heat.

6.1.4 Electric panel heaters



Description

Units are wall mounted and operate off standard rate electricity to provide a variable heat output, using thermostatic control.

Energy efficiency

100% of delivered electrical energy input.

Controls

- Thermostatic control, mounted on unit
- Some models available with 24h programme timers for individual control.

Maintenance implications

None.

Advantages

- Simple and quick to install
- Low capital cost
- Small size of units.

Disadvantages

- Very high fuel cost compared with gas and off-peak electricity, leads to high running cost, despite unit efficiency.

Applications

- Offices with small heat load, eg internal rooms
- Provision of 'top-up' heat to rooms with electric storage heaters.

6.1.5 Air conditioning

General

The use of air conditioning in AFU Office Areas, for comfort cooling, cannot be justified in terms of energy efficiency. However, its use may be dictated by:

- High external ambient noise levels or pollution levels, precluding the opening of windows for natural ventilation
- High internal heat gains
- Process requirement
- Marketing image of building.

This Guide does not cover the subject of air conditioning in depth: reference should be made to the *CIBSE Guide*[12] and other publications for futher information.

6.2 Office Area ventilation

All ventilation provisions must meet the statutory minima outlined in Section 2.2 and elsewhere. Reference should be made to the *CIBSE Guide*[12] for full guidance.

The energy efficient solution is the provision of natural ventilation via controllable openings.

Mechanical ventilation may be necessitated by the size, depth and orientation of the offices, or by the requirements to control the quality of the air supplied, or to isolate the interior from external noise and airborne pollutants.

6.3 Office Area lighting

Generally, fluorescent lighting is the most suitable for offices. Many different types of fluorescent lamps exist, and development is continuing at present particularly of high frequency fittings and compact fittings. Reference should be made to manufacturers' data for individual specifications.

Use of light coloured surface finishes will increase lighting levels.

Select luminaires with high efficiency reflectors - these maximise light output and can reduce lighting costs.

In developing an energy efficient lighting scheme, switching facilities should:

- Incorporate separate perimeter switching to allow switching off in periods of bright daylight
- Have sufficient flexibility to allow modification into zones by the occupant
- Use special fittings for vdu installations etc
- Be clearly labelled.

7 Environmental systems selection - Production Area

7.1 Key charts

A series of three key charts is provided to assist the designer in selection of systems, for a range of different activities outlined below. The key charts note the principal points to be considered with each combination of activity and system. Further details of each system are given in subsequent Sections.

7.2 Production Area activities

The following list covers the majority of the activities likely to take place in the Production Area of AFUs. Many end uses may cover more than one activity: in this case, the designer should select a system suitable for all the activities; where this is not practicable, each activity or area should be physically separated, and considered individually - for example:

- A goods receiving area in a warehousing unit
- A foreman's office in a workshop area.

7.2.1 Warehousing/storage

Storage with low level racking or high bay racking, generally with little or no occupancy.

7.2.2 Light industry, general (excluding electronics)

All activities involving sedentary or light work, for which staff are sitting or standing at benches or small production lines, with the exception of work with sensitive electronic components.

7.2.3 Light industry involving electronic components

Activities involving the manufacture, assembly, use or repair of sensitive electronic components, where excessive air movement or dust transmission is undesirable, eg television assembly.

7.2.4 Manual workshop

All activities or processes involving heavy manual work, eg fitting shop, tyre repair bay, where the acceptable space temperature is lower than is needed for normal sedentary work.

7.2.5 Fume production activities

Any activity involving the evolution of fume, dust and other airborne contamination. This ranges from work giving off contamination from many sources in the area to a single source confined to one area, such as a welding pen.

7.2.6 Partitioned-off goods receiving/despatch

Part of the Production Area partitioned off for goods handling, that may require only background heating.

7.3 Production Area heating

For a summary of system selections, refer to the key chart given in Table 7.3. Each system referenced is described in the Sections following.

General illustrations of each system appear below:

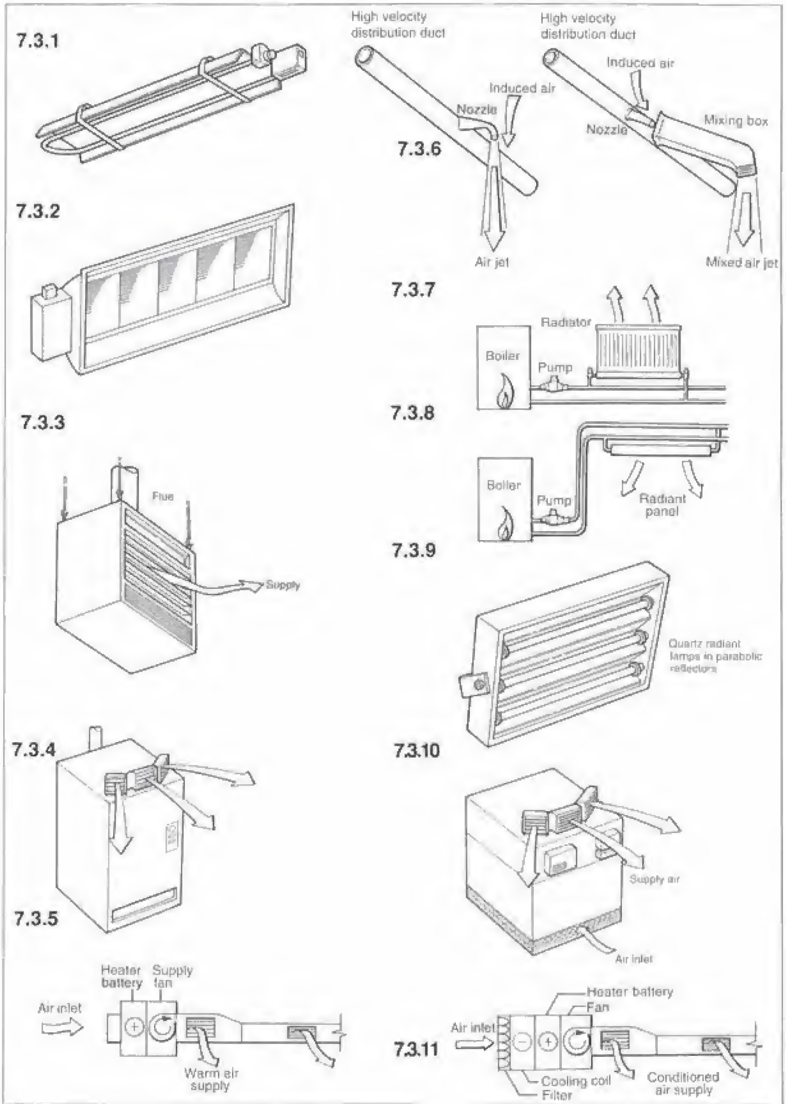


Table 7.3 Production Area heating system options - key chart

		Warehousing/ storage	Light industry - general	Light industry - electronic	Manual workshop	Fume production activities	Partitioned off goods receiving/ despatch
Heating system options							
Flued — Applicable to direct or indirect gas-fired systems only		○	○	○	○	8	◒
Unflued		●	5	●	○	○	○
Gas- fired							
7.3.1 Overhead radiant tube heaters	- Flued	1	○ (11)	5	○	(8,12)	◒
	- Unflued	●	4,5	●	○ (4)	4,12	○
7.3.2 Radiant plaque heaters	- Unflued only	○ (4)	4	●	○ (4)	4,12	○
Gas- or oil -fired							
7.3.3 High level unit heaters*	- Flued	○	○ (8)	7	○	8	◒
	- Unflued	●	4	●	○ (4)	○ (4)	○
7.3.4 Floor standing warm air heaters*	- Flued	○	○ (8)	● (6)	○	8	◒
	- Unflued	●	4	●	○ (4)	○ (4)	○
7.3.5 Ducted warm air systems		3	3	7	3	●	9
7.3.6 Warm air jet/induced jet systems	- Flued	3	3	7	3	●	9
	- Unflued	●	4	●	4	4,12	9
7.3.7 Radiators and convectors served by boiler		3	3	3	●	○	●
7.3.8 Radiant panels served by boiler		○ (3)	○ (3,11)	○	◒	○ (3)	9
Electric							
7.3.9 Overhead radiant heaters		2	2,11	2	2	2	2
7.3.10 Storage warm air heaters*		○ 10	○ 10	○ 10	●	●	●
Air conditioning							
7.3.11 Air conditioning*		3	3	3,7	●	●	●

Key references:

* Consider specification of destratification equipment with these heating systems.

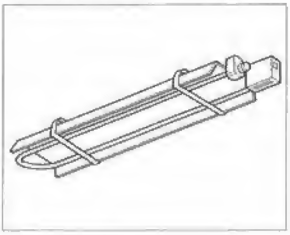
1. Not generally suitable for use with high bay racking due to proximity of stored goods to heaters. Beware also presence of inflammable materials.
2. Suitable for spot heating applications: high running costs with standard tariff electric heating.
3. High capital costs: suitable for particular applications with special requirements.
4. Suitable with high ventilation rate. Needed to avoid increase in relative humidity.
5. Careful specification of burner tube required to avoid metal flaking problem.
6. Generally not suitable due to high air velocities and transmission of dust.
7. Suitable, but care needed to avoid high velocities and transmission of dust.
8. Careful specification of heat exchanger materials to avoid chemical attack from fumes such as degreasers, aerosols etc.
9. Not suitable unless branched off system serving main area.
10. Suitable for highly insulated well sealed buildings. Running costs comparable with oil and propane fuels. Suitable for heating small areas such as foreman's office etc. where other forms of heating not practical. High running costs on standard tariff.
11. High radiant temperatures not suitable for printing applications.
12. Not suitable with inflammable fumes.

Note: Activities refer specifically to areas, ie. foreman's office or goods receiving area may require different type of heating to main area.

KEY			
	○ Suitable	◒	Not necessary
	● Not suitable	1,2 etc	See key reference

7.3 Production Area heating

7.3.1 Gas-fired overhead radiant tube heaters



Description

These heaters are suspended at high level from roof steelwork or wall mounted. Gas is burnt in a tube, causing the tube to emit radiant heat. The reflector focuses the heat to ground level. The products of combustion are extracted from the tube by a vacuum fan, and this can be connected to a flue to discharge outside. Units vary from the simple U-tube to interconnected systems with a common extract fan, and high/low burner control. Mounting heights can vary from 3.5m to 25m, and thus can be suitable for a wide variety of building heights. Other features available from some manufacturers include:

- Stainless steel emitter tubes, used in critical applications where cleanliness is important
- Internal swirlers for optimum heat exchange
- Solid end brackets to reduce convection loss.

A combustion air inlet in the building fabric must be provided for flued units.

Energy efficiency

Standard U-tube systems operate at approximately 80% efficiency, rising to approximately 90% efficiency for interconnected systems. Heat output is predominantly radiant, which is absorbed directly by the body, hence the heating effect is produced without heating the air. With radiant systems, air temperature can be kept lower for the same comfort level compared with convective systems, hence less energy is used. Rapid heat up reduces preheat period (typically 0.25h compared with 1.0 - 2.0h for a warm air system).

Controls

A 'black bulb' thermostat measures the radiant temperature and controls the U-tube burner. On/off burner control is standard fitment, but some manufacturers can supply high/low burner control, which provides a measure of modulation of radiant output.

Maintenance implications

Burners require twice yearly maintenance to ensure correct combustion and continued reliability. Because of high level mounting, access for servicing is inconvenient.

Advantages

- High level mounting means no floor space used and occurrence of accidental damage minimised
- Energy efficient
- Fast heat-up rate means rapid temperature recovery, eg following goods door opening
- Lower air temperature for same comfort level: lower energy costs
- No air movement or dust transmission.

Disadvantages

- Some types of heater are noisy
- Poor maintenance access
- Oversized systems can produce uncomfortable radiant temperature fluctuations
- Radiant heat can cause discolouration of materials.

Applications

Flued systems suitable for most applications, including:

- Sedentary work: care to be exercised to avoid local hot spots under burner tubes. Consider high/low burners to limit radiant temperature fluctuations
- Well sealed buildings with low air change rates (***Note***: permanent ventilation for combustion air must be provided)
- High bay buildings
- Especially suited to activities demanding low air movement
- Local 'spot' heating.

Unflued systems are suitable for areas with high ventilation rates, eg:

- Loading bay areas
- Areas not susceptible to high humidity levels.

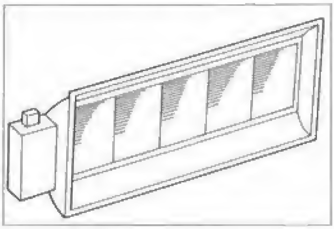
Care should be taken when specifying this type of system where:

- Electrical components are manufactured/assembled. Measures should be taken to ensure that metal flaking of the tubes does not occur
- Combustible materials are present
- Discolouration of materials may occur.

These heating units are not suitable for:

- Printing applications
- Activities which give off large amounts of compounds containing sulphur or chlorine: dry cleaning fluids, degreasing fluids, PVC, cutting oils, some aerosols
- Low mounting heights (below 3.5m).

7.3.2 *Gas-fired radiant plaque heaters*



Description

The units comprise ceramic plaques mounted in polished reflectors. Natural gas or propane is burned in the plaque assembly, and the radiant heat emitted is reflected to ground level. Because the radiant temperature is greater than that of the U-tube type heaters, the units are smaller for the same power output. Control is via a 'black bulb' radiant temperature sensor. Mounting heights vary from 4.0m to 10.0m.

Energy efficiency

Efficiencies in excess of 90% are achieved with these units. Particularly efficient for spot heating applications, and for high bay situations.

Controls

A 'black bulb' thermostat measures the radiant temperature and provides on/off control to the heater plaques. Some manufacturers supply multiple plaque units, enabling a degree of output modulation for switching off some plaques in each unit.

Maintenance implications

Burners require twice yearly maintenance to ensure correct combustion and continued reliability. Because of high level mounting, access for servicing is inconvenient.

Advantages

- Small and lightweight
- Fast heat-up rate
- High efficiency, low running costs
- High mounting position means no floor space used, and occurrence of accidental damage minimised
- No air movement caused by heating system.

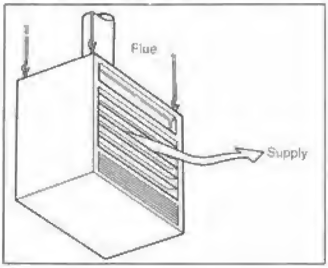
Disadvantages

- Products of combustion emitted into heated space. If used as main heating system, high ventilation rates needed to prevent condensation (especially in well sealed low energy AFUs)
- Poor servicing access
- Radiant heat can cause discolouration of materials.

Applications

- Most industrial activities except for sedentary work, where high radiant temperature may cause discomfort
- Particularly useful for situations where mounting space is restricted, eg above crane gantries etc
- Ideal for 'spot' heating needs in large unheated areas
- Intermittent use
- Not suitable for printing applications owing to high radiant temperatures
- See Section 7.3.1 *Applications* for those applications where care is required and those where these heating units are not suitable.

7.3.3 High level unit heaters



Description

These units are installed between 2.5m and 5.0m high suspended from roof steelwork, although some units are suitable for base mounting. Unflued units burn natural gas, propane or oil directly in the air supplied to the space. Flued units burn the fuel in a heat exchanger warming the supply air which is then discharged horizontally via a fan, or distributed via ductwork. The combustion products from the heat exchanger are discharged to outside via a flue. A combustion air inlet in the building fabric must be provided.

Higher efficiency semi-condensing units are available, these having a secondary heat exchanger and fan assisted flue/combustion air inlet. Horizontal flue arrangements are possible. A condensate drain is required.

Pulse combustion units, burning natural gas or propane are also available, these operating at high efficiency. A condensate drain and air inlet and flue pipes are required.

The heat output is predominantly convective. In high buildings (over 6m to eaves) care must be taken to avoid warmed air rising into the roof space and stratifying. Consider use of destratification fans. If the discharged warm air is directed downwards, this could result in a zone of uncomfortable hot and fast moving air adjacent to the unit. It could also lead to inadequate heat distribution.

Most units can be used for summer 'cooling', by operation with the burner switched off.

Energy efficiency

Flued units operate at approximately 75 - 80% efficiency. Unflued units and semi-condensing units operate at 85 - 90% efficiency, and pulse combustion units operate at up to 95% efficiency. These units are an energy efficient solution especially for lower height buildings (up to 5m to eaves). Modulating burners are available, which match heat output to heat load, hence reducing fuel consumption.

Controls

On/off or modulating control (depending on specification) of burners is provided by room thermostats situated at low level (1m high) or by return air thermostats, mounted on the unit.

Maintenance implications

Burners require twice yearly maintenance to ensure correct combustion and continued reliability. Owing to high level mounting, access for servicing is inconvenient.

Advantages

- No use of floor space
- Better heat distribution can be achieved compared with floor standing units
- Air discharge pattern on some units can be adjusted to suit differing layouts
- Mounting height reduces damage risk.

Disadvantages

- Predominantly convective heat, therefore stratification can occur in high buildings. Consider destratification fans
- Higher dry bulb temperatures required to achieve same comfort level as equivalent radiant systems. Can increase energy consumption
- Air movement required to distribute heat. This can cause uncomfortable hot zones adjacent to heaters if proper consideration is not taken in design layout
- Access for servicing inconvenient
- On/off mode of burner control can cause uncomfortable temperature fluctuations adjacent to unit
- More noisy than radiant systems.

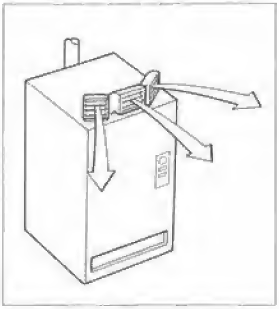
Applications

Flued systems suitable for most applications including:

- Sedentary work: particular care to be taken to distribute heat effectively avoiding high air velocities, hot zones and cold zones
- Light industrial work: avoid high air velocities and excessive temperature gradients
- Heavy manual work
- Storage/warehousing.

Unflued systems suitable for areas with high ventilation rates. Processes involving the production of fumes need special consideration.

7.3.4 *Floor standing warm air heaters*



Description

These units are generally the cheapest system to purchase and install. Unflued units burn natural gas, propane or oil directly in the air supplied to the space. Flued units burn the fuel in a heat exchanger warming the supply air which is then discharged horizontally via a fan. The air discharge louvres are adjustable, allowing the air flow to be directed as required. Alternatively, the supply air can be distributed via ductwork. The combustion products from the heat exchanger are discharged to outside via a flue. Consider use of destratification fans to assist air circulation. A combustion air inlet in the building fabric must be provided for flued units.

Energy efficiency

Flued units operate at approximately 75 - 80% efficiency (85 - 90% efficiency for unflued units). Modulating burners are available, which match heat output to heat load, hence reducing fuel consumption.

Controls

On/off or high/low/off or modulating control (depending on specification) of burners is provided by room thermostats situated at low level (1m high) or by return air thermostats, mounted on the unit.

Maintenance implications

Burners require twice yearly maintenance to ensure correct combustion and continued reliability. Access for servicing is good.

Advantages

- Low capital cost
- Low installation cost
- Flexibility - units can be moved relatively easily to suit new layouts
- Good access for maintenance.

Disadvantages

- Floor space use
- Predominantly convective heat, hence stratification can occur especially in high buildings (consider destratification fans)
- High dry bulb temperatures required to achieve same comfort level compared with radiant systems. Increases energy consumption

- Air movement required to distribute heat. This can cause uncomfortable zones adjacent to the discharge of high velocity hot air
- Noisy
- Vulnerability to damage.

Applications

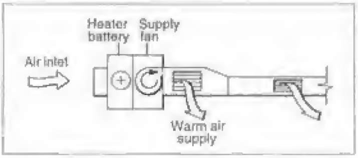
Flued systems suitable for:

- Light industrial work, taking particular care to avoid high air velocities and excessive temperature gradients
- Heavy manual work
- Storage/warehousing.

Unflued systems suitable for areas with high ventilation rates.

Activities involving the emission of fumes need special consideration.

7.3.5 *Ducted warm air systems*



Description

In simplest form, these are systems in which warm air is distributed to one or more points via ductwork. The warm air may be supplied by a variety of means: from standard unit heaters to purpose built air handling units which incorporate a heater battery or burner, fans, filters and silencers. More complex systems incorporate fresh air supplies and extract as part of a balanced ventilation system (refer also to Section 7.4.5).

Energy efficiency

- Efficiency depends upon heat source and system design
- In balanced systems (ie, where fresh air is supplied and warmed air exhausted) heat recovery should be considered to make use of waste heat.

Controls

Room thermostats provide control to the heater battery or burner, which is usually fully modulating.

Maintenance implications

Gas- or oil-fired burners require twice yearly maintenance to ensure correct combustion and continued reliability. Access for servicing depends on the location of the air handling unit. Location outside the working area is advantageous.

Advantages

- Good heat distribution
- More controllable environment than other systems, depending on specification.

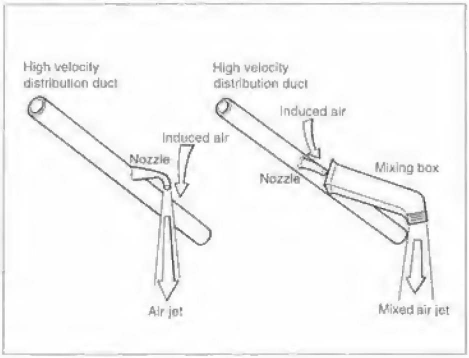
Disadvantages

- High capital cost.

Applications

- Production Areas which are partitioned into smaller areas, with sedentary activity taking place
- Areas where a higher quality environment is required.

7.3.6 Warm air jet/induced jet systems



Description

An air handling plant supplies hot air to small diameter high velocity distribution ductwork mounted at high level. The air handling plant may be directly fired by gas or oil (flued or unflued), or indirectly supplied via a hot water or steam coil from a gas- or oil-fired boiler situated elsewhere. Electrically heated systems are also available. Specifications can include fully recirculating or full fresh air systems. With both systems, air is discharged downwards from the distribution ductwork through purposely designed jet nozzles and mixes with the surrounding air. Induced jet systems employ a mixing box in which primary and secondary air is mixed before being discharged to the space. The mixed air is discharged at lower temperature and velocity, but greater momentum can be achieved than with nozzles alone; hence these systems are used where longer throws are required, eg in higher buildings.

Energy efficiency

- Inherently destratifying - avoids waste heat at high level
- Overall efficiency depends upon efficiency of heat source.

Controls

Room thermostats provide control to the heater battery or burner, which is usually fully modulating.

Maintenance implications

Gas- or oil-fired burners require twice yearly maintenance to ensure correct combustion and continued reliability. Access for servicing depends on the location of the air handling unit. Location outside the working area is advantageous.

Advantages

- Variety of heating media can be used
- Inherent destratification
- Excellent conditions produced: good temperature distribution, low air velocities, low noise levels
- Small diameter ductwork - can be mounted in roof depth
- Moving parts confined to air handling plant: no disruptive maintenance at high level
- Summer fresh air ventilation available (depending on specification)
- Air handling plant can be located outside working space.

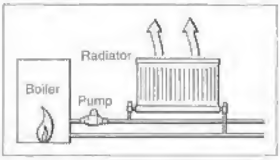
Disadvantages

- High capital cost
- Air movement used to transfer heat, although velocities at ground level lower than other warm air systems.

Applications

- Most activities
- Particularly suited to high bay areas, high bay storage, and where good quality environmental conditions are required.

7.3.7 Radiators and convectors served by boiler



Description

Hot water is circulated from an oil- or gas-fired boiler to radiators*, fan convectors (low level) or unit heaters (high level). The boiler may be of conventional or more efficient condensing type[16,20]. The hot water supplied to radiators is generally Low Temperature Hot Water (LTHW) at approximately 80°C, and supply to fan convectors is usually Medium Temperature Hot Water (MTHW), at approximately 110°C.

* Despite the name, radiators emit predominantly *convective* heat.

Energy efficiency

- Depends upon boiler efficiency and system design
- Efficiency can be maximised by using condensing boilers where possible, and incorporating energy saving controls.

Controls

Room or radiator mounted thermostats provide local control: the boilers and heating system have central control. Staged boiler output to match the heating load is possible using step control of modular boilers or high/low or modulating burner control on larger boilers.

Maintenance implications

Gas- or oil-fired burners require twice yearly maintenance to ensure correct combustion and continued reliability. System needs occasional inspection.

Advantages

- Flexible layout
- Good temperature control achievable
- Small size of heat emitters
- Heating plant can be located outside working area.

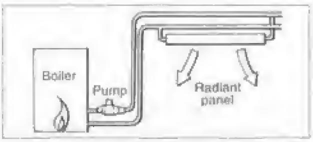
Disadvantages

- Relatively high capital cost
- Pipework and emitter equipment prone to damage unless situated at high level
- Convective heat emission can result in stratification
- Heat distribution by air movement
- Fan assisted units can be noisy
- Slow heat-up compared with direct or radiant systems
- Efficiency reduced by boiler standing losses and pipework losses.

Applications

- Radiator systems suitable for applications where space volume can be reduced by installation of false ceilings (to reduce heat loads)
- Fan convectors and unit heaters suitable for most applications except for those with high air change rates. Use of destratification fans should be considered (particularly with fan convector installations).

7.3.8 Radiant panels served by boiler



Description

Medium temperature hot water (MTHW) at approximately 110°C is circulated from an oil- or gas-fired boiler to radiant panels mounted at high level. The panels emit radiant heat, warming occupants and objects at floor level.

Energy efficiency

Depends upon efficiency of heat source, system design and equipment specification. Efficiency can be increased by using condensing boilers, insulated pipework, and good quality radiant panels which incorporate insulation on top surface to reduce convective losses.

Controls

A 'black bulb' thermostat senses the radiant temperature and provides control to the boiler. Temperature is modulated by varying water flow.

Maintenance implications

Gas- or oil-fired burners require twice yearly maintenance to ensure correct combustion and continued reliability. System needs occasional inspection.

Advantages

- Good temperature control possible
- No air movement required to distribute heat
- High level mounting reduces damage risk to heat emitters.
- Heating plant can be situated outside working area
- Rapid temperature recovery, eg after opening goods door.

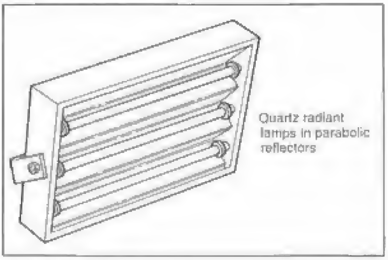
Disadvantages

- High capital cost
- Slow heat-up from cold, compared with other radiant systems.

Applications

- Most activities
- High bay buildings
- Particularly suitable for heating fume laden atmospheres
- High radiant temperatures not suitable for printing applications.

7.3.9 Electric radiant heaters



Description

These heaters comprise quartz lamps fitted in a polished reflector. The lamps emit radiant heat which can be directed to the area required. Heat-up to full power is instant in switching on. Mounting heights vary from 2m to 4m.

Energy efficiency

The lamps operate at 100% efficiency of delivered electrical energy input, but use standard rate electricity.

Controls

A 'black bulb' thermostat senses the radiant temperature and provides control to the heater, switching on and off lamps as necessary.

Maintenance implications

Low maintenance.

Advantages

- Fast heat-up rate
- Small and lightweight
- Simple and cheap to install
- High level mounting: no floor space used, and occurrence of accidental damage minimised
- Low maintenance
- No air movement
- Easily relocated to suit new layout or new building
- No fumes produced.

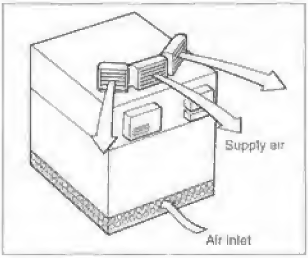
Disadvantages

- Standard rate electricity is used - high running cost can result with high heat load.

Applications

- When used as sole source of heating, suitable for well insulated buildings with low air change rates. Care to be taken when considering for sedentary activities to avoid uncomfortably high radiant temperatures
- Intermittent use
- Spot heating in larger unheated areas
- Process drying/heating requirements
- Temporary or mobile installations
- Not suitable for printing applications due to high radiant temperatures.

7.3.10 Electric storage warm air heaters



Description

Based on the same principle as domestic storage heaters, these units use Economy 7 low rate electricity to heat a brick core. This heat is then released, on demand, during the day. The air from the core is mixed with ambient air and supplied via a fan to the space at a suitable temperature. As the core cools, a damper adjusts to pass more air through the core, hence maintaining the supply temperature.

Weather compensating charge controllers are available which adjust the amount of night time charge taken depending on external conditions.

Consider the use of destratification fans to assist air circulation.

Energy efficiency

Nearly 100% efficiency of delivered electrical energy input when weather compensated controls used. Losses limited to casing loss (typically less than 1%) during night charging; if unit is in heated space, emission is utilised.

Controls

Room thermostat provides control to the unit which modulates the heat output.

Maintenance implications

Low maintenance.

Advantages

- Easy to install and operate
- Quiet operation
- High efficiency
- No pipes, flues, combustion air inlets required
- Weather compensation control means energy used only on demand.
- Low maintenance
- Units can be moved to suit new layout/new building.

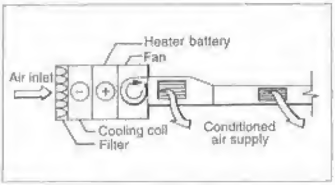
Disadvantages

- Large unit, takes up floor space
- Poor heat distribution unless multiple units used
- High running costs compared with natural gas
- Air movement required to distribute heat, which can cause uncomfortable hot zones adjacent to units
- Convective heat output, hence stratification can occur, especially in high buildings (consider destratification fans)
- Vulnerability to damage.

Applications

- Viable alternative to oil or propane fuels in terms of installation and running cost, particularly in well insulated buildings
- Most industrial activities, except where high ventilation rate is needed.

7.3.11 Air conditioning



Description

Air supplied to the treated space is filtered, humidified or dehumidified, and heated or cooled as required, in order to maintain the environmental conditions within the space between specified limits.

Equipment ranges from small units for conditioning single rooms through to centralised plant serving whole buildings via distribution ductwork.

Air conditioning may be divided into two categories: that required for 'comfort' cooling of occupants, and that needed to maintain specific conditions imposed by process or equipment.

Controls and maintenance implications vary with the complexity of the system.

Energy efficiency

Air conditioning is not energy efficient compared with a conventional heating system with natural ventilation. Normally, it cannot be justified for comfort cooling alone.

Applications

Equipment such as computers, or certain processes may impose limits for dust levels, humidity and temperature which dictate the use of air conditioning.

If air conditioning is required, the following should be noted:

- Minimise conditioned volume (build room to house equipment or processes) to minimise size of air conditioning plant
- If possible avoid specifying narrow ranges for environmental conditions (eg, min temp 20°C, max temp 21°C), as this increases energy consumption
- Consider zoning requirements.

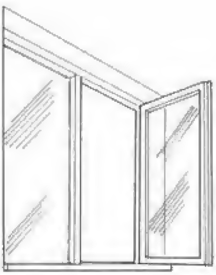
7.4 Production Area ventilation

There is a wide variety of ventilation systems to suit an equally wide variety of ventilation requirements. The basic types of ventilation are shown below, and selections for a number of typical activities appear in the key chart given in Table 7.4.

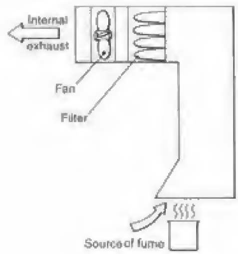
Each system referenced is described in the Sections following.

General illustrations of each system appear below:

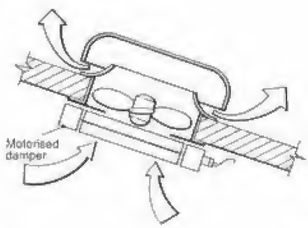
7.4.1



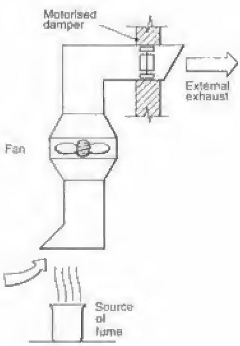
7.4.4



7.4.2



7.4.3



7.4.5

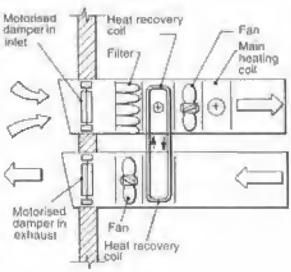


Table 7.4 Production Area ventilation system options - key chart

Ventilation system options	Warehousing/ storage*	Light industry - general	Light industry - electronic	Manual workshop	Fume production activities	Partitioned off goods receiving/ despatch
7.4.1 Natural ventilation	○	○ (1)	● (2)	○ (1)	● (3)	○
Extract ventilation						
7.4.2 Summer vent/general vent (roof or wall mounted extract fans)	○	○	○ (2)	○	○	◒
7.4.3 Fume/dust local extraction to outside	◒	○ (4)	○ (5)	○ (4)	○ (4)	◒
7.4.4 Fume/dust local filtered extraction, recirculated	◒	○ (4)	◒	○	○ (6)	◒
7.4.5 Balanced ventilation	◒	○ (6)	○ (7)	◒	○	◒
7.3.11 Air conditioning	●	○ (8)	○ (8)	●	●	●

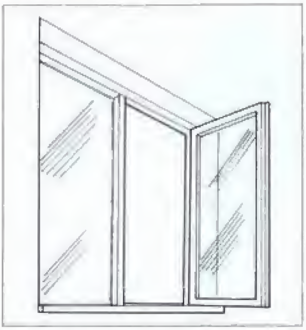
Key references:

* Ventilation may be required for certain types of stored items eg. foodstuffs and paints. In these cases, ensure good circulation between aisles and shelves.

1. Adequate ventilation based on number of occupants must be provided.
2. Consider sensitivity based on number of electronic components of air movement and dust transmission.
3. Extraction required.
4. If fume or dust is produced in small quantities.
5. If fumes are produced, local extract required. Consideration to be given to balanced ventilation to avoid introducing contamination by creating a negative pressure in a space with a number of extracts.
6. Avoids drawing in uncontrolled quantities of external air. For use with larger extraction volumes.
7. Need to consider filtration and tempering of incoming air.
8. Necessary only for activities requiring close environmental control, including filtration, cooling and dehumidification.

KEY			
○	Suitable	◒	Not necessary
●	Not suitable	1,2 etc	See key reference

7.4.1 *Natural ventilation*



Description

Achieved by opening doors and windows, in addition to the building air infiltration and leakage.

Energy efficiency

Air infiltration and leakage is uncontrolled, hence losses may be high, adversely affecting energy efficiency if heating is on.

Controls

Manual.

Maintenance implications

None.

Advantages

- No capital cost.

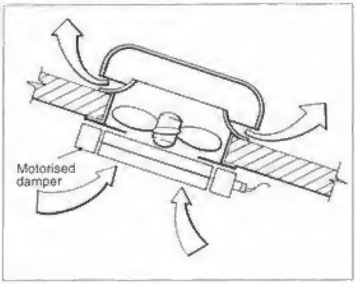
Disadvantages

- Ventilation rate may be insufficient to cater for occupants or processes. Fume and dust not dealt with effectively. High heat losses.

Applications

- Factories with low occupancy
- Offices

7.4.2 Roof or wall extract fans



Description

Mounted in the roof, or at high level in the walls, fans extract contaminated or warm air, providing general fume ventilation or summer ventilation. For summer ventilation, it is usual to provide extraction capacity equivalent to 4 air changes per hour, based on the building volume.

Energy efficiency

If used for general fume extract, heat losses will be high, adversely affecting energy efficiency.

Controls

Manual switching.

Maintenance implications

Low maintenance requirement, but access inconvenient when servicing needed.

Advantages

- Low capital costs
- Very effective for controlling summer temperatures.

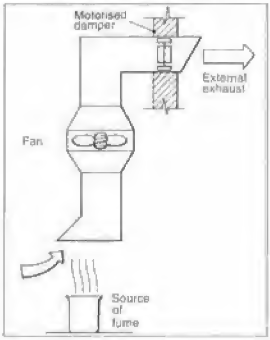
Disadvantages

- Sources of fume or dust not dealt with effectively
- Large heat losses if this method used to control fume concentrations.

Applications

- Summer ventilation of most light industrial situations that do not require more stringent environmental control (dust, humidity, temperature). This type of ventilation generally should not be used as the only means of fume ventilation. The exceptions are where fume sources are small, or of low toxicity, or where an excess of heat is produced by the process.

7.4.3 Local extraction to outside



Description

Extraction at source of airborne contaminants from processes. With a small number of extract points or a low overall volume, a tempered make-up supply is not required. For large extraction volumes, supply make-up can be delivered close to the extraction point although care should be taken to minimise local reduction in temperature and creation of draughts. (Draughts may reduce capture efficiency.)

Energy efficiency

Potentially a most efficient form of ventilation.

- Minimise extraction volume
- Consider heat recovery from extracted air
- Supply untreated make-up air as close as possible to extraction point.

Controls

Manual switching.

Maintenance implications

Where systems are installed to control the level of airborne contaminants as a requirement of the *Control of Substances Hazardous to Health (COSHH) Regulations*[3], then there is a requirement (under Regulation 9.1) for regular maintenance, thorough examination and testing.

Advantages

- Pollutants can be extracted at source
- Lower volumes of heated air wasted than with general ventilation system.

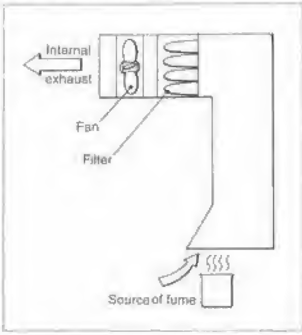
Disadvantages

- Extraction hoods must be placed close to source, necessitating installation of ducting etc
- For large air volumes extracted, heat loss can be significant. Consider heat recovery to temper incoming supply air
- Large heat losses if this method used to control fume concentrations.

Applications

- All activities or processes involving production of fume or dust. Specialist advice required.

7.4.4 Local extraction, recirculated



Description

Airborne contaminants extracted at source, and passed through a filter before being returned to the working space.

Energy efficiency

Potentially very efficient because no heat is lost to outside.

Controls

Manual switching.

Maintenance implications

Where systems are installed to control the level of airborne contaminants as a requirement of the *Control of Substances Hazardous to Health (COSHH) Regulations*[3], then there is a requirement (under Regulation 9.1) for regular maintenance, thorough examination and testing.

Advantages

- No heat loss.

Disadvantages

- Filter requires frequent cleaning
- Limited to small quantities and non toxic emissions.

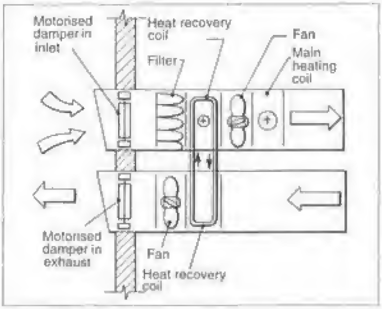
Applications

- Application requires specialist advice to ensure that the actual or potential source of increased exposure to the worker does not increase the risk to health
- Application generally limited to the emission of small quantities of non toxic, low concentration fume or dust
- If fumes are hot consider:

  downward distribution of recirculation air in winter

  changeover to atmospheric discharge in summer.

7.4.5 Balanced ventilation



Description

A volume of tempered supply air is introduced into the space to balance the extracted air.

In critical areas the volume of supply air can be slightly higher than extracted, maintaining the area at slightly higher pressure, to avoid the ingress of dust.

The requirement for balanced ventilation will depend upon application.

Energy efficiency

Energy efficiency can be improved by utilising heat recovery from exhaust air to temper incoming air.

Controls

Manual switching starts both parts of system.

Maintenance implications

Fans have low maintenance requirement. Regular cleaning or replacement of filters essential to maintain effectiveness.

Applications

- Balanced ventilation may be required for a variety of processes or equipment.

7.5 Production Area lighting

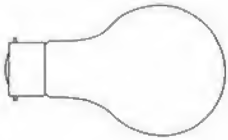
The key chart given in Table 7.5 contains a summary of lamp selections suitable for a variety of activities. Each lamp type is described in the Sections following. This information is derived partly from the *CIBSE Lighting Guide: The industrial environment*[14].

The lamp will provide the basic characteristics of the light output, such as colour rendering and colour appearance. The luminaire, comprising the reflector, diffuser (if fitted) and housing, controls the manner in which the light is distributed and controlled, and the level of comfort level achieved.

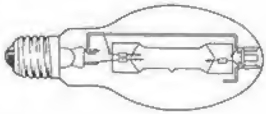
High efficiency reflectors should be used where possible, as these can significantly reduce lighting costs.

General illustrations of each lamp appear below:

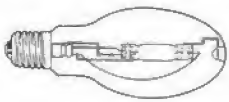
7.5.1



7.5.2

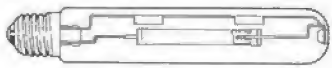


7.5.3



7.5.4

7.5.5



7.5.6

Table 7.5 Production Area lighting system options - key chart

Lighting system options	Warehousing - high bay	Warehousing - low bay	Light industry	Manual workshop	Fume production activities	External
7.5.1 Tungsten filament (GLS)	● (8)	● (8)	● (8)	● (8)	● (8)	● (8)
7.5.2 High pressure mercury	○ (6,1)	○ (6)	○ (6)	○ (6)	○ (5)	○ (6)
7.5.3 Metal halide	○ (1)	○	○ (4)	○	○ (3)	○ (4)
7.5.4 Tubular fluorescent	○ (1,5)	○ (5)	○ (2)	○	○ (3)	●
7.5.5 High pressure sodium	○ (1)	○	○ (6)	○	○ (3)	○
7.5.6 Low pressure sodium	●	●	●	●	●	● (7)

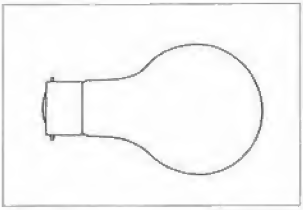
Note: Consider effects of ignition time and restrike time for all lamps except fluorescent.

Key references:

1. Use fittings which provide vertical illumination on the faces of the racking, with separate switching on each aisle, preferably at the entrance to each aisle.
2. Need to consider colour rendering and glare in specification of fittings.
3. Consider corrosion protection and spark or flame proof fittings (level of protection and safety will depend upon nature of fume or dust).
4. Suitable where good quality white light is required.
5. Consider movement control.
6. Acceptable where colour rendering is not important. Generally superceded by metal halide or high pressure sodium.
7. Acceptable where colour rendering is not required, such as security lighting.
8. Suitable only for emergency lighting and hand lamps.

KEY			
○	Suitable	◒	Not necessary
●	Not suitable	1,2 etc	See key reference

7.5.1 Tungsten filament (GLS)



Description

A tungsten filament is heated to incandescence inside a glass envelope producing white light. Most of the energy input is emitted in the form of heat, and hence the lamps operate at low efficacy. Operating life about 1000h.

Energy efficiency

Poor efficacy, typically 8-18 lumens/watt.

Advantages

- Instant switching on and off
- Excellent colour rendering
- Versatile.

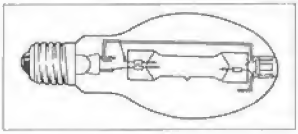
Disadvantages

- Poor efficacy, high running cost
- Short operating life.

Applications

- Emergency lighting
- Hand lamps
- Not suitable for general use lighting because of low efficacy and resultant high running cost.

7.5.2 *High pressure mercury (MBF, MBFR)*



Description

A high pressure mercury vapour discharge operates in a quartz arc tube. The internal surface of the outer elliptical bulb is coated with a phosphor which converts ultra-violet radiation from the discharge into light.

Fair colour rendering. Ignition time 5-7 mins, and restrike time 2-7 mins.

These lamps have generally been superceded in new installations by metal halide or high pressure sodium lamps, which provide significantly better efficacies and light quality.

Energy efficiency

Good efficacy, typically 35-54 lumens/watt.

Advantages

- Low cost compared to sodium lamps
- Long life, typically 5000 - 24 000h
- Efficacy.

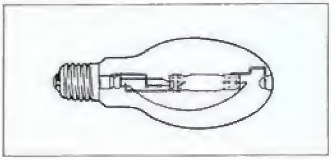
Disadvantages

- Fair colour rendering
- Light output falls with age, reducing efficacy.

Applications

- All industrial situations where colour rendering is not of prime importance
- Some types available where minimum maintenance is required
- External lighting.

7.5.3 Metal halide (MBI, HPI)



Description

An electrical discharge in a high pressure mercury atmosphere with metal halide additives in an arc tube, sometimes contained within a glass envelope. Ignition time 5 mins, restrike time 10 mins.

Energy efficiency

High efficacy, typically 66-84 lumens/watt.

Advantages

- Good colour rendering
- Efficacy
- Life, typically 4000 - 12 000h.

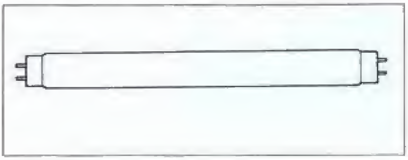
Disadvantages

- Long restrike time
- Higher cost compared with MBF lamps.

Applications

- All industrial applications, including ones where good colour rendering is important
- High bay areas
- Area floodlighting, external lighting.

7.5.4 Tubular fluorescent (MCF)



Description

The tube contains mercury vapour at low pressure. An arc emits ultra-violet energy which is converted into light by the coating of fluorescent phosphors on the tube. Compact fittings now available, suitable for replacement of tungsten filament lamps.

High frequency fittings are available, at higher cost, that improve energy efficiency and provide a dimming facility.

Energy efficiency

High efficacy, typically 37-100 lumens/watt.

Advantages

- Efficacy
- Immediate ignition and restrike
- Low cost
- Good to excellent colour rendering (depending on specification of fluorescent coating)
- Life, typically 5000 - 15 000h.

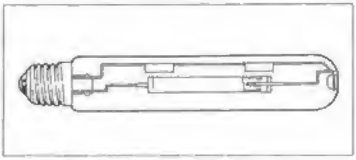
Disadvantages

- Lower output per lamp compared with high pressure sodium and metal halide lamps
- Not as suitable for high bay installation.

Applications

- Most industrial applications, mainly low bay
- Offices
- Compact fittings suitable as replacements for tungsten lamps.

7.5.5 High pressure sodium (SON)



Description

These lamps operate with an arc formed in high pressure sodium vapour. Reasonable colour rendering. Ignition time 5-7 mins, restrike time, 1 min.

Available in a wide range of outputs to suit a variety of applications.

Energy efficiency

Very high efficacy, typically 67-137 lumens/watt.

Advantages

- Efficacy
- Short restrike time
- Lamp gives off 'warm' light (predominantly yellow end of spectrum)
- Long life (6000 - 24 000h) and little fall off of light output with age
- Wide range of lamp outputs
- Can operate at low temperatures (- 40° C).

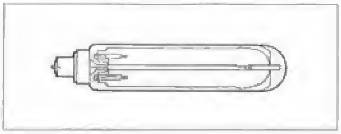
Disadvantages

- Higher cost compared with MBF lamps.

Applications

- Most industrial lighting applications, including high bay applications
- Flood lighting, street lighting
- Particularly suitable in situations where access is difficult or expensive.

7.5.6 Low pressure sodium (SOX)



Description

A low pressure sodium discharge in an arc tube emits a monochromatic yellow light. Ignition time approximately 10 mins.

Energy efficiency

Very high efficacy, typically 101-190 lumens/watt.

Advantages

- Efficacy
- Long life, typically 5000 - 20 000h.

Disadvantages

- Total lack of colour rendering restricts application.

Applications

- Road lighting and security lighting.

8 Performance monitoring

8.1 Purpose

It is in everyone's interest to ensure that the installed systems are working at maximum efficiency. Performance monitoring can be carried out simply and takes very little time. Year-to-year comparisons can show the financial benefits of system improvements and, conversely, can indicate degradation of performance, enabling faults in the system to be recognised and dealt with.

Consideration should be given at the design stage to facilitating performance monitoring. Separate meters can be provided for process and space heating, lighting etc.

8.2 Advisory publications

Further free information on performance monitoring in factories and warehouses[23] is available from the Energy Efficiency Office. The *CIBSE Energy Code Part 4*[15] also contains useful information on performance monitoring.

The Table below[23] gives an energy efficiency rating for factory and warehouse buildings.

- **Good** - buildings falling in this category have generally good controls and energy management procedures, but further energy savings are often possible.
- **Fair** - energy consumption in this band indicates reasonable controls and energy management procedures, but significant energy savings should be achievable.
- **Poor** - Energy consumption is unnecessarily high and urgent action should be taken to remedy the situation. Substantial energy savings should result from the introduction of energy efficiency measures. There may be valid reasons why energy consumption is the high, e.g. the inclusion of process energy in meter readings used. The likely contribution to space heating from process energy losses should be considered, as this may rise to a good or fair performance in an otherwise inefficient building.

The Normalised Performance Indicator (NPI), calculated using the documented method[23], takes account of floor area, weather, exposure and hours of use. It can then be compared with the Performance Yardsticks below.

Performance Yardsticks for factory and warehouse building (gross floor area basis) (kWh/m² per year)

	Energy efficiency rating		
Type of site	**Good**	**Fair**	**Poor**
Factories with little or no process energy requirement			
- small, less than 2000m² (*Note 1*)	less than 230	230-300	more than 300
- large, more than 2000m²	less than 260	260-370	more than 370
Factories with heat gains from manufacturing plant (*Note 2*)			
- small, less than 2000m²	less than 190	190-270	more than 270
- large, more than 2000m²	less than 210	210-300	more than 300
Warehouses, heated	less than 150	150-270	more than 270

Notes on Performance Yardsticks table:

1 Small low energy factory units with a high standard of insulation should only use about 85 kWh/m^2 for space heating.

2 The yardsticks exclude energy used for the process energy itself.

3 The average height assumed for the above building types are:

Factories	8.0m
Warehouses	8.0m.

4 1 kWh is equal to 3.6 MJ.

9 References and further information

Note: The references below are not intended to form a comprehensive list.

9.1 Statutory regulations and standards

The following are available from HMSO bookshops:

1 *Factories Act 1961.*

2 *Energy Act 1976 and Statutory Instrument 1980/1013 (Amending SI 1974/2160).*

3 *Control of Substances Hazardous to Health (COSHH) Regulations 1989.*

4 **Department of the Environment and the Welsh Office.** *The Building Regulations Approved Documents L: Conservation of fuel and power* 1990;
Or **The Scottish Office.** *Technical Standards, For Compliance with the Building Standards (Scotland) Regulations 1990. Part J: Conservation of fuel and power.* Edinburgh, HMSO, 1990;
Or **Department of the Environment for Northern Ireland.** *The Building Regulations (Northern Ireland) 1990. Technical Booklet F: Conservation of fuel and power.* Belfast, HMSO, 1990.

5 *British Standards* (various).

6 *Health and Safety at Work etc Act 1974.*

9.2 Guidance publications - general

7 **Health and Safety Executive (HSE).** Ventilation of the workspace. *HSE Guidance Note EH22*, revised May 1988. Available from HMSO bookshops.

8 **HSE.** Occupational exposure limits. *HSE Guidance Note EH40/91*, 1991. Available from HMSO bookshops.

9 **Building Services Research and Information Association (BSRIA).** A design briefing manual. *BSRIA Application Guide* 1/90 Bracknell, BSRIA, 1990. BSRIA, Old Bracknell Lane West, Bracknell, Berkshire, RS12 4AH; tel 0344 426511; fax 0344 487575.

10 **Scurry P.** Quality assurance in building services. *BSRIA Technical Memorandum* TM 1/83. Bracknell, BSRIA, 1983.

11 **British Standards Institution.** British Standard Code of practice for energy efficiency in buildings. *British Standard* BS8207: 1985. London, BSI, 1985. Available from HMSO bookshops.

12 **Chartered Institution of Building Services Engineers (CIBSE).** *CIBSE guide.* London, CIBSE, 1986. CIBSE Delta House, 222 Balham High Road, London, SW12 9BS; tel 081 675 5211; fax 081 675 5449.

13 **CIBSE.** *CIBSE Code for Interior Lighting.* London, CIBSE, 1984.

14 **CIBSE.** The industrial environment. *CIBSE Lighting Guide:* LG1. London, CIBSE, 1989.

15 **CIBSE.** *CIBSE Building Energy Code Part 4: Measurement of energy consumption and comparison with targets for existing buildings and services.* London, CIBSE, 1982.

16 **CIBSE.** Condensing boilers. *CIBSE Applications Manual* AM3. London, CIBSE, 1989.

17 **CIBSE.** Energy audits and surveys. *CIBSE Applications Manual* AM5. London, CIBSE, 1991.

18 **The Institution of Electrical Engineers (IEE).** *Regulations for electrical installations. Sixteenth Edition 1991.* Stevenage, IEE, 1991. IEE, PO Box 96, Stevenage, Herts SG1 2SD.

19 **O'Reilly J J N.** Better briefing means better buildings. *Building Research Establishment Report BR 95.* Garston, BRE, 1987. BRE, Garston, Watford WD2 7JR; tel 0923 664444; fax 0923 664010.

20 **Building Research Establishment.** Condensing boilers. *BRE Digest* 339. Garston, BRE, 1988.

21 **Building Research Establishment.** Lighting controls and daylight use. *BRE Digest 272.* Garston, BRE, 1983.

22 **Hughes D.** Energy efficient factories: design and performance. *Building Research Establishment Information Paper* IP 13/89. Garston, BRE, 1989.

9.3 Guidance publications - Energy Efficiency Office

Available *free* from the Department of Environment, Blackhorse Road, London SE99 6TT:

Energy efficiency in buildings series

23	Factories and warehouses	IEB63
24	Offices	IEB56

Fuel efficiency booklets

25	Energy audits	IFEB1
26	Economic use of fired space heaters	IFEB3
27	Economic use of electricity	IFEB9
28	Controls and energy savings	IFEB10
29	Energy management and good lighting practices	IFEB12
30	The recovery of waste heat from industrial processes	IFEB13
31	Economic use of oil-fired boiler plant	IFEB14
32	Economic use of gas-fired boiler plant	IFEB15
33	Economic thickness of insulation for existing industrial buildings	IFEB16
34	Economic use of coal-fired boiler plant	IFEB17

9.4 Building Research Energy Conservation Support Unit (BRECSU) publications

Available *free* from BRECSU, Building Research Establishment, Garston, Watford, WD2 7JR; tel 0923 664258; fax 0923 664097.

35	Low energy factory development	EPP 173
36	Low energy factory development	Final Report No. ED/256/173
37	Insulated factory loading doors	EPP 334
38	Energy efficiency in industrial buildings	IL 9
39	*Energy efficiency in lighting in factories and warehouses: Good Practice Guides* (to be published) Low ceiling industrial buildings High ceiling industrial buildings Warehouses	
40	*Energy efficiency in lighting in factories and warehouses: Good Practice Case Studies*(to be published)	GPCS
41	*Energy efficiency in offices: Good Practice Case Studies* *Energy efficiency in offices: Energy Consumption Guide* A technical guide for owners and single tenants	GPCS (Various) ECON 19

9.5 Further information and bibliography

42 **Health and Safety Executive.** Private communication, 1990.

43 **Jones P J and O'Sullivan P E.** Energy efficient design of industrial buildings, *Building and Environment 1987,* **22** (3) 181-187.

44 **Jones P J, Pearson J, Reed M C, and White V**. Comfort heating in modern low energy factories. *56th Autumn Meeting and Gas 90 Exhibition, 1990.* Available from the Institute of Gas Engineers, 17 Grosvenor Crescent, London SW1X 7ES.

Appendix A Building tests on completion

The means by which built quality is verified are well established in building research fields. Three principal tests are outlined below:

A1 Infra-red thermography surveys

An infra-red scanner is used to detect infra-red radiation emitted by objects and surfaces. The amount of radiation given off increases with higher surface temperatures. The scanner can detect the difference in radiation levels and converts these into a 'heat picture' of the subject, where lighter areas are warmer and dark areas represent a colder surface[1].

This enables visualisation of cold bridges and air infiltration in a building. It is possible to identify areas of missing or defective insulation, and cold bridging caused by sheeting rails, internal gutters etc.

The equipment used comprises a portable, usually hand-held, infra-red scanner and monitor/ recorder. Thermographic images can be taken from inside and from outside the building, to fully record the sources of heat loss. The data recorded can be edited, enabling selected frames, indicating problem areas, to be printed.

In a large warehouse type building, the survey takes 2-3 hours to complete.

Aerial surveys can be used to scan large roof areas or groups of buildings, or occupied buildings where the internal view of the structure is obscured. However, the level of detail obtained may not be as great.

A2 U-value test

The U-value of roof or wall constructions can be assessed by monitoring the heat flow through a representative area of the surface. To ensure that the heat flow through the area measured is representative of the rest of the wall or roof, the surface is first examined with the infra-red scanning system to identify an area of suitably uniform thermal performance.

The equipment comprises internal and external surface temperature sensors, and internal and external air temperature sensors. The data from the sensors are recorded on two dataloggers over a period of 7-10 days. The resulting U-value is an average value which takes into account the dynamic effects of the thermal response of the construction.

Currently, this test is used for research purposes only, and is not yet suitable for commercial use as a contract requirement. Development of equipment giving both quick and accurate measurement of U-value is underway at present.

A3 Infiltration test

There are two methods for assessing the infiltration rate of a building.

- **Pressurisation test**

  This test uses a fan to pressurise the building to establish the leakage rate for a given pressure differential[2]. The data from the test cannot be directly converted to an infiltration rate although, recently, research[3] has been undertaken to establish a mathematical model which provides a link between leakage measurement and infiltration rate. It can be difficult to ensure representative results using this test: a typical problem is that of pressurised air venting through the roof extract fans (unless motorised dampers are fitted).

- **Tracer gas decay test**

  This test measures the decay of a tracer gas injected into the air, giving the rate at which the air is being replaced, or infiltration rate[4]. In order to obtain a statistically valid result, several tests would have to be undertaken under a variety of external conditions, as the ventilation rate will vary with wind speed and direction, and external temperature. However, an approximate indication of the building leakiness can be obtained from a single test.

A4 References

1 **Hart J M.** An introduction to infra-red thermography for building surveys. *Building Research Establishment Information Paper* IP/790. Garston, BRE, 1990. BRE, Garston, Watford WD2 7JR; tel: 0923 664444; fax: 0923 664010.

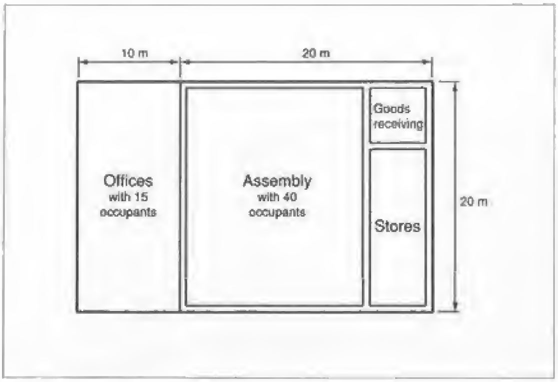
2 **Perera MDAES, Stephen R K** and **Tull R G.** Use of BREFAN to measure the air tightness of non-domestic buildings. *Building Research Establishment Information Paper* IP6/89. Garston, BRE, 1989.

3 **Perera MDAES, Powell G, Walker R R** and **Jones R J.** Using pressurisation measurements to predict ventilation performance and heating energy requirements of a large industrial building. *Building Research Establishment Paper PD160/90 for 11th AIVC Conference.* Garston, BRE, 1990.

4 **Walker R R** and **Perera MDAES.** The BRESIM technique for air infiltration rates in large buildings. *Building Research Establishment Information Paper* IP11/90. Garston, BRE, 1990.

Appendix B Typical Advance Factory Unit sample selections for construction and services: capital and running costs

The following are selections for a theoretical building of 600m² floor area with a height-to-eaves of 6m. The Production Area contains a Goods Receiving Area, a Storage Area and an Assembly Area with sedentary type activity, where visual tasks are moderately difficult.



B1 Construction costs

Comparative costs for different forms of construction and different design U-values are given below. Costs are *approximate only* and are based on the following typical construction. Actual costs may vary significantly from these, being dependent on many other factors.

Construction Type 'A'

Lower walls:	facing brick	
	medium-density blockwork	
	partial cavity insulation	(U = 0.45 W/m²K)
	or full cavity insulation	(U = 0.3 W/m²K)
Upper walls and roof:	profiled steel outer sheet	
	insulation quilt	
	steel liner panel	
Floor:	uninsulated	(U = 0.32 W/m²K)
Glazing:	single-glazing	(U = 5.6 W/m²K)
	or double-glazing	(U = 3.2 W/m²K)

Construction Type 'B'

Cavity walls as for Type 'A' above.

Upper walls and roof:	factory-made composite	
Floor:	uninsulated	($U = 0.32$ W/m²K)
Glazing:	single-glazing or double-glazing	($U = 5.6$ W/m²K) ($U = 3.2$ W/m²K)

Table B1 Comparative construction costs (1991 base)

	Construction type				
	A			B	
U-value (W/m²K)	0.45		0.3	0.45	0.3
	Cost (£)	Cost ratio			
Foundations		No significant difference			
Frame		No significant difference			
Floor slab *	20 000	100(base)	109	100	109
Dado walls	12 500	100(base)	102	100	102
Wall cladding	10 500	100(base)	109	125	141
Roof cladding	14 600	100(base)	106	125	142
Total	57 600	100(base)	107	111	122

* The cost increase for the floor slab is based on the inclusion of perimeter floor slab insulation; this is not actually required, as the slab is large enough to have a satisfactory *overall* U-value. However, the majority of the heat losses occur at the edge of the slab. Hence, incorporation of perimeter insulation can reduce these losses, and minimise the likelihood of condensation arising from the cold bridge at the slab edge.

B2 Environmental services

Referring to Section 4, *Design Criteria*, the following values for temperature, ventilation and lighting can be obtained:

Table B2 Design values for environmental services

	Office Area	Assembly Area	Storage Area	Goods Receiving Area
Temperature (°C)	20-22	19-21	15-19	16-19 (if permanently occupied)
Ventilation (m^3/s)	0.12*	0.32 for whole area, (based on floor area)		
Light level (lux)	500	500	150	150

* based on number of occupants

Note: Capital and running costs (based on 1991) quoted below are approximate only, for the arbitrary activity and building used in this example. Actual costs are dependent upon many factors such as hours of operation, process environmental requirements, tariffs etc., and can vary significantly from the values quoted. These values should not be used for estimating purposes.

B2.1 Office Area

B2.1.1 Heating

The heat loss for the unit constructed to a U-value of 0.45 W/m^2K, incorporating single-glazing, is 18kW; for construction to 0.3 W/m^2K, and double-glazing, 15 kW.

Suitable office heating systems include:

Gas convector heaters (6.1.1)
Low temperature hot water radiator systems (6.1.2)
Electric storage heaters (6.1.3).

High running cost would preclude the use of electric panel heaters (6.1.4).

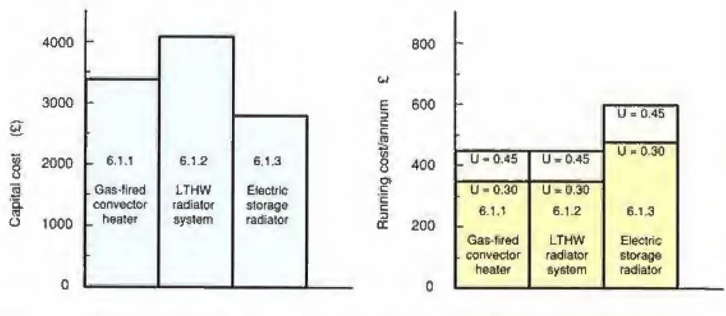


Figure B1 Comparative costs for Office Area heating systems

Note: These values are indicative only.

B2.1.2 Ventilation

The ventilation requirement of 0.12 m^3/s, based on the recommended fresh air supply per person of 8 l/s, equates to an air change rate of 0.72 ac/h: this can be met by natural ventilation.

B2.1.3 Lighting

Fluorescent lighting, using 14 twin lamp 60W fittings, will provide 500 lux at the working plane, at a capital cost of approximately £2500; running cost amounts to approximately £250/year.

B2.2 Production Area

B2.2.1 Heating

The heat loss for the unit constructed to a U-value of 0.45 W/m^2K is 34 kW; for construction to 0.3 W/m^2K, 31 kW.

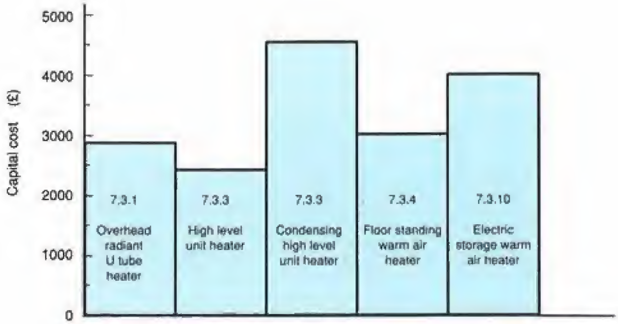
Referring to Table 7.3, for general light industry (Assembly Area):

- Unflued direct-fired oil or gas systems are not suitable with low ventilation rate.

- Suitable heating systems:
  Overhead radiant tube heaters (7.3.1)
  High level unit heaters (7.3.3)
  Floor standing warm air heaters (7.3.4): if carefully designed to avoid excessive air movement at low level.
  Electric storage warm air heaters. (7.3.10).

- Ducted warm air systems (7.3.5), warm air jet/induced jet systems (7.3.6), radiators and convectors served by boiler (7.3.7) and radiant panels served by boiler (7.3.8), would not be viable owing to high capital cost. Overhead electric radiant heaters (7.3.9) are not suitable for low bay heating, and running costs would be high. Air conditioning (7.3.11), is not required as there are no processes or equipment imposing stringent environmental conditions.

Comparisons of approximate capital and running costs, and seasonal efficiencies, for the heating systems are given below.



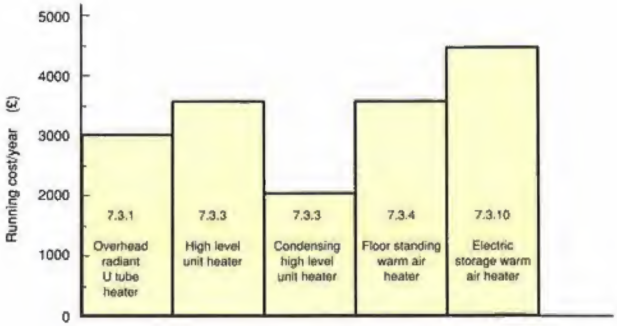


Figure B2 Comparative costs for Assembly Area heating systems

Note: These values are indicative only.

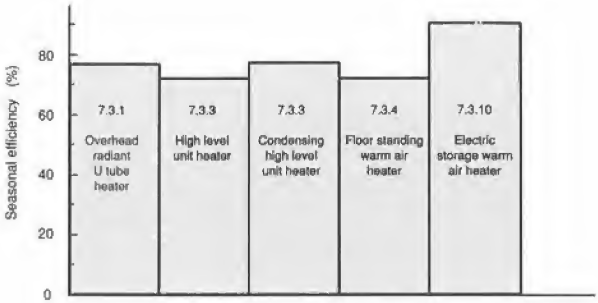


Figure B3 Comparative seasonal efficiencies for Assembly Area heating systems

Note: These values are indicative only.

The Storage Area is too small to be considered for a separate heating system. Maintenance of a different temperature in this area would require a partition to be installed to avoid cold air movement into the Assembly Area.

Owing to the proximity of the Goods Receiving Area to the Assembly Area, some means of avoiding cold draughts onto the sedentary occupants of the Assembly Area will be required (see Section 4.3). If the area is partitioned off, the Goods Receiving Area can be treated separately in terms of heating requirements. Suitable systems would include:

Overhead radiant tube, flued or unflued (7.3.1).
Radiant plaque (7.3.2).
High level unit heater, flued or unflued (7.3.3).
Overhead electric radiant heater (for 'spot' heating) (7.3.9).

Comparisons of approximate capital and running costs, and seasonal efficiences, for the heating systems are given below.

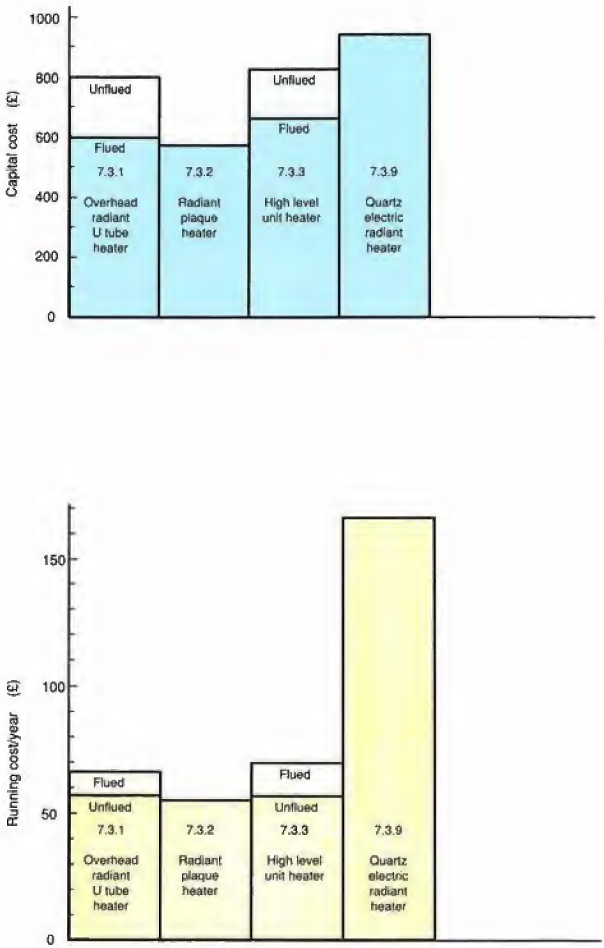


Figure A4 Comparative costs for Goods Receiving Area heating systems

Note: These values are indicative only.

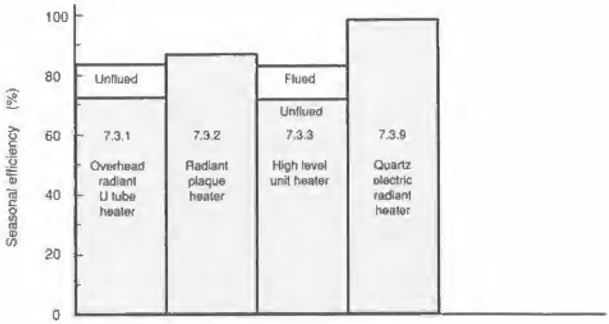


Figure A5 Comparative seasonal efficiencies for Goods Receiving Area heating systems

Note: These values are indicative only.

B2.2.2 Ventilation

The ventilation requirement of $0.32m^3/s$, based on the minimum fresh air supply per m^2 floor area of 0.8 l/s, equates to an air change rate of 0.48 ac/h. The natural infiltration rate for this size of building is 1 ac/h, and hence this covers the ventilation requirement.

B2.2.3 Lighting

Suitable lighting for the Assembly Area can be supplied by metal halide (7.5.3), tubular fluorescent (7.5.4) or high pressure sodium (7.5.5) lamps. High pressure mercury (7.5.2) lamps would not be suitable because of their poorer colour rendering properties.

The Goods Receiving Area and Stores Areas can be lit by the same choice of lamps, although colour rendering may not be as important, hence high pressure mercury may be used.

Comparisons of capital and running costs, and efficacy, for the lighting systems for the total area are given below.

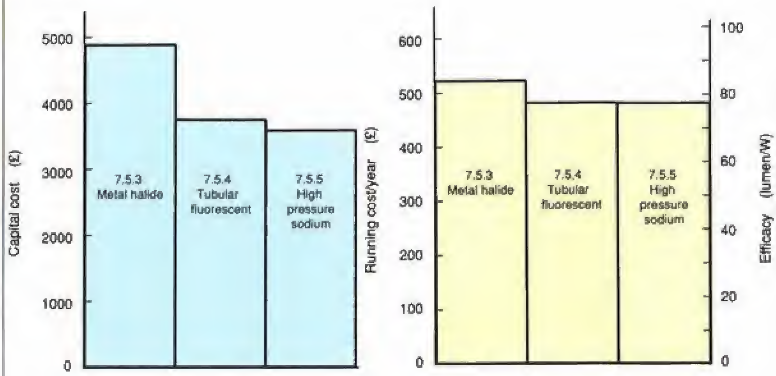


Figure A6 Comparative costs and efficiencies for lighting systems for Production Area

Note: These values are indicative only.

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